BMW Rivnut® Remover

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DESIGN, ANALYSIS, AND PROTOTYPING OF A RIVNUT® REMOVER

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Mechanical Engineering

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by
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- Machining and Technical Services of Clemson University - for providing quotes for custom parts of final design

EXECUTIVE SUMMARY

Many vehicles require the installation of a special fastener called a Rivnut®. These fasteners are useful because they allow threaded components to be attached to sheet metal. They are inserted into a hole and a tool pulls the Rivnut®, causing it to collapse against the sheet metal. This process makes a compressed ring that causes the Rivnut® to be tight against the vehicle and allow a threaded component to be inserted into it. Some failure modes for these Rivnuts® include becoming cross threaded or they freely spin in the hole. In either of these cases, the Rivnut® must be removed. The current process for removing the Rivnut® is to drill through it, causing the back of it to fall into the vehicle. This process also leaves the head of the Rivnut® on the hole, which must be pried off and also leaves the compressed ring on the threaded part of the Rivnut®, making it impossible to come through the hole in which it was installed. If the Rivnut® or the back of it cannot be removed in a timely manner, the BMW automobile continues to be assembled and is sent to the rework station after it has completed assembly. This vehicle may have to be disassembled in some areas in order to retrieve the back of the Rivnut® or remove the Rivnut® entirely. This wastes BMW's time and money.

The new method and tool must completely remove the Rivnut® in under two minutes, without causing any scratching, denting or marring to the surface. In addition, the new design must be light and small enough for an associate to handle it with ease.

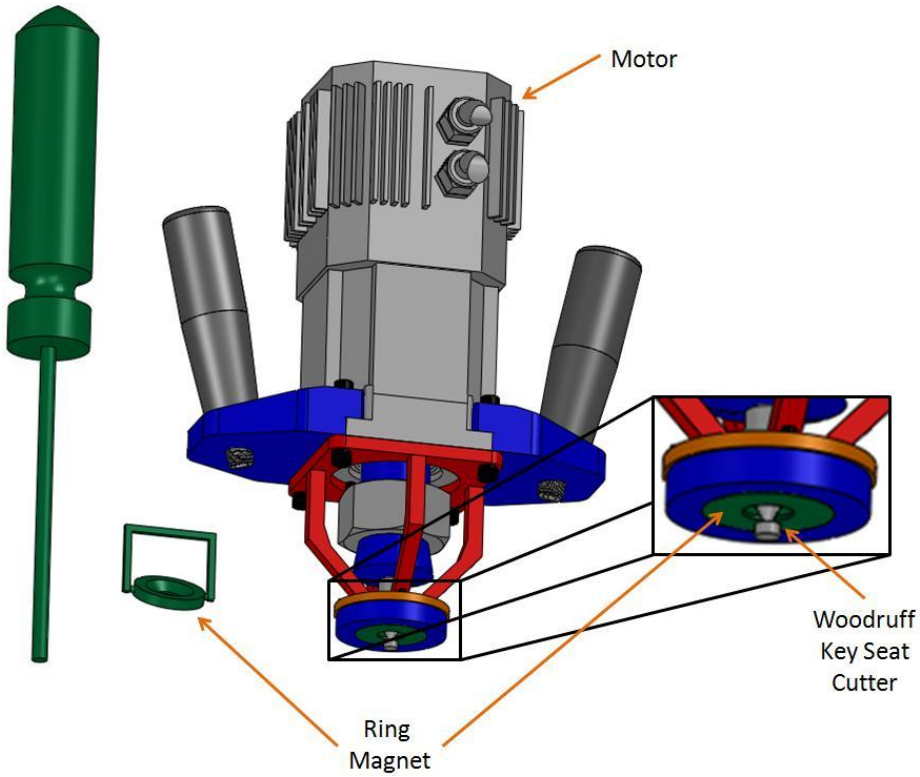

Figure 1: Recommended Solution.

The recommended solution is shown in Figure 1. This design consists of a motor that rotates a woodruff key seat cutter that rides along a circular path to cut out the compressed ring of material. It also uses a powerful magnet to catch the once threaded portion of the Rivnut® from falling in the vehicle after it has been cut off.

To remove a Rivnut®, one must follow a series of steps.

1. Place the ring magnet over the Rivnut® to be removed, shown in Figure 2.
2. Using a "K" size drill bit, drill out the Rivnut® threads to make room for the woodruff key seat cutter, shown in Figure 3.
3. Place the tool around the ring magnet. This will place the woodruff key seat cutter inside the Rivnut® and cutting may begin when the tool engages the Rivnut®, shown in Figure 4.
4. Move the tool in a circular pattern, provided by the base. Once the tool has completed a full rotation, the threaded end of the Rivnut® is cut off.
5. Remove the tool from the vehicle. The threaded end of the Rivnut® is caught by the ring magnet along with any shavings produced, shown in Figure 5.
6. Using a "T" size drill bit, drill out the head of the Rivnut®, show in Figure 6.
7. Place the rod magnet inside the hole to remove threaded end of the Rivnut® as well as any shavings, shown in Figure 7.
8. Remove the ring magnet and install a new Rivnut®.

Figure 2. Placement of Magnet.

Figure 3. Drilling Threads.

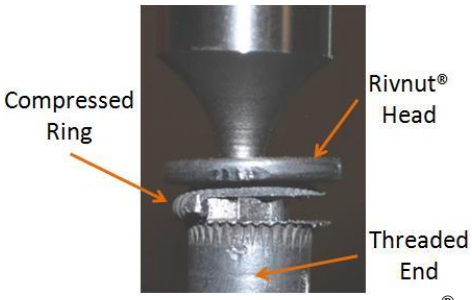

Figure 4. Cutting Out Rivnut®.

Figure 5. Magnet Ability.

Figure 6. Drilling Rivnut® Head.

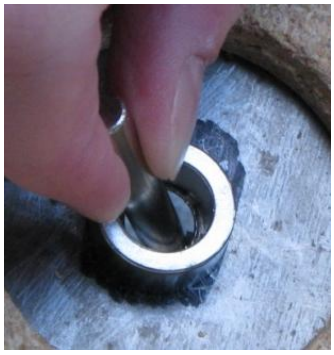

Figure 7. Rod Magnet Insertion.

Using this method and the prototype, 88% of the Rivnuts® tested were removed in an average time of 112 seconds (one pass). All of the Rivnuts® were not removed successfully because the prototype requires two passes to completely remove the compressed ring. In the first pass, the bottom half of the compressed ring is cut off. The second pass is required to cut the top half of the compressed ring; however, while making the second pass, the top half of the compressed ring spreads apart instead of being cut. This is the cause for the unsuccessful removal attempts. This is solved in the final design when the cutter face width is doubled, resulting in only one pass to remove the compressed ring.

The final design meets all the constraints and the proposed design solution will cost approximately $2211. Associates can be taught how to remove a Rivnut® using this tool and method in under an hour.

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INTRODUCTION

Rivnuts® are sometimes poorly installed during the assembly process. If the Rivnut® is unable to be removed in the line, a note is made in the computer system and the car continues to be assembled. After the vehicle is assembled, the vehicle is taken to the rework station where associates must remove the damaged Rivnut®, which may involve disassembling other components in order to reach the Rivnut®. These measures take up valuable time and can incur significant costs. BMW is seeking a tool or fixture that can easily remove these damaged Rivnuts® quickly and effectively.

Problem Statement

Design a tool and method to completely remove cross-threaded or slipping Rivnuts® from sheet metal without causing damage to the base material including scratching, marring, or denting.

Constraints

The final design must:

- Weigh less than 6.8 kg
- Remove a Rivnut® in less than 120 seconds
- Be no larger than (50.8 x 25.4 x 25.4) cm
- Meet all of OSHA's safety(pinch points) and ergonomic constraints
- Not alter base material/finish in any way
- Must be able to remove a Rivnut® from a 5.08 x 5.08 cm area

Criteria

The final design should:

- Remove Rivstuds®
- Weigh less than 4.5 kg
- Be available to the consumer at $500 or less
- Be usable by the Rivnut® installer personnel

RECOMMENDED DESIGN CONCEPT

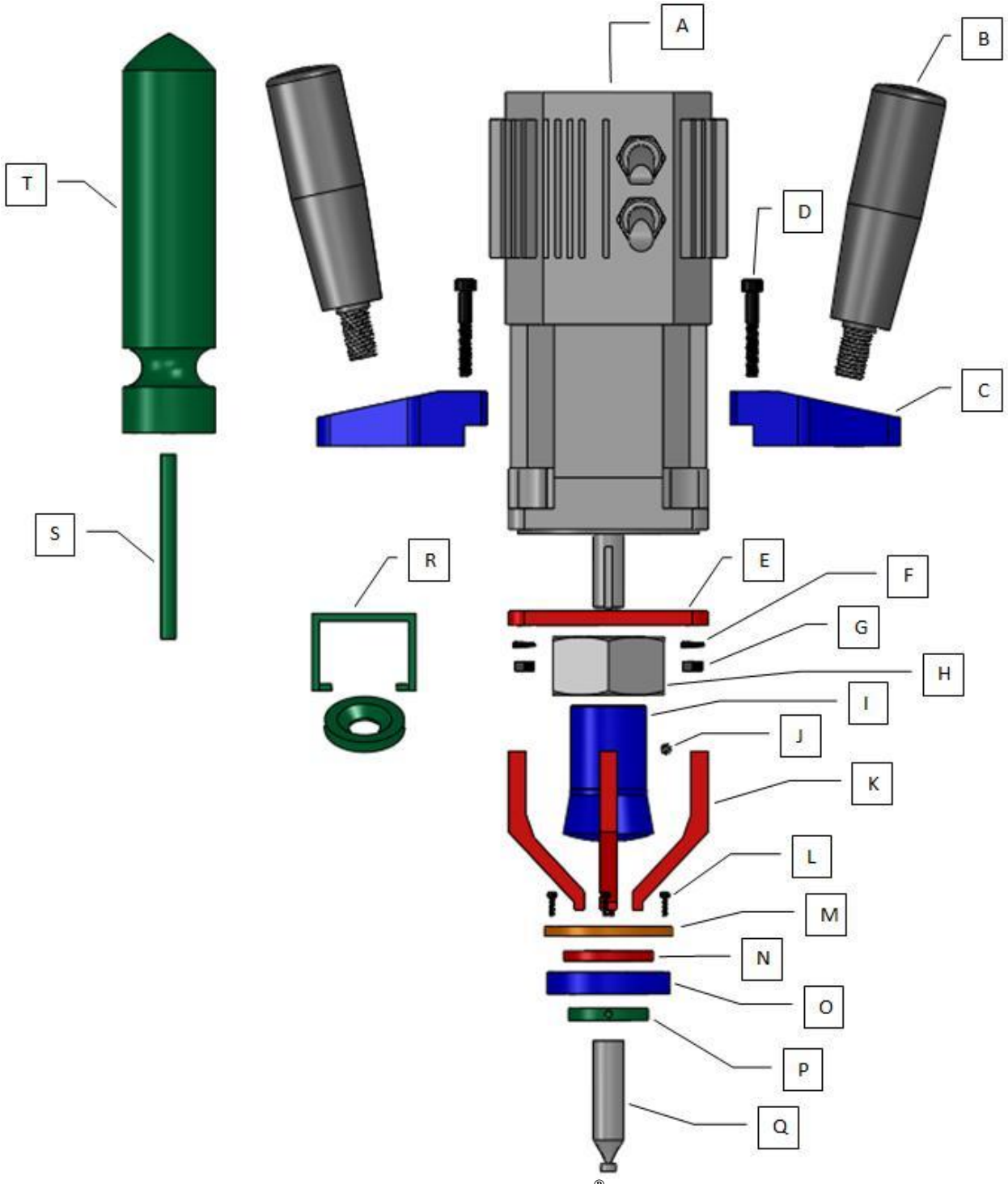

Figure 8. Exploded view of Rivnut® Removal Tool.

An exploded view of the recommended design solution is shown in Figure 8. Parts A-T mentioned in this section can be found in this figure, while parts U-X are mentioned in Appendices N and M. Appendix N

contains the bill of materials which shows the cost of these parts and where they can be obtained. Detail drawings of each component can be found in Appendix M.

The plunge router in Figure 9 is replaced by Parts A-I in the final design solution. These parts in the final design solution are much smaller so the tool is lighter, and easier to maneuver.

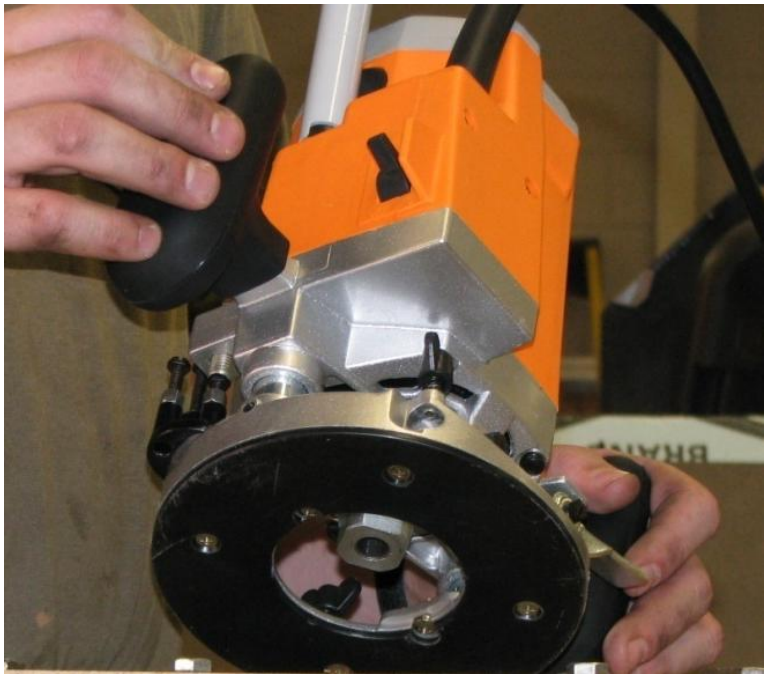

Figure 9. Plunge Router.

Part (A) is a Brushless DC Motor that runs on 120-VAC using an integrated speed controller. This motor generates 13.4 in-lbs of torque which is 257% greater than the minimum required 5.2 in-lbs needed to cut a Rivnut® using the technique illustrated in Appendix O. This motor also rotates from 0-1750 RPM which is around the suggested 1681 RPM provided by the woodruff key seat cutter manufacturer.

Part (B) is the handle which will provide the user with enough leverage to easily maneuver the tool during operation. The metal handles are covered by a layer of phenol formaldehyde resin which protects anything the tool handles may encounter unpredictably. This resin layer will also protect the handles from becoming dinged which could result in sharp burrs that could injure the associate or mar the vehicle.

Part (C) is the handle mount which is made from 1060 aluminum alloy and provides a rigid connection between the handles and the motor.

Parts (E), (K), and (N) are the motor mount top, legs, and bottom respectively. These pieces are made from 1060 aluminum alloy and are welded together. The mount will be bolted to the motor for rigidity. The bottom section acts as the follower in a cam-follower style operation.

Parts (H) and (I) are custom collet nuts and collets respectively. Since a key-shaft is used on the motor, a custom collet was created, which resulted in a custom collet nut. A collet is necessary to mount the cutting tool to the motor.

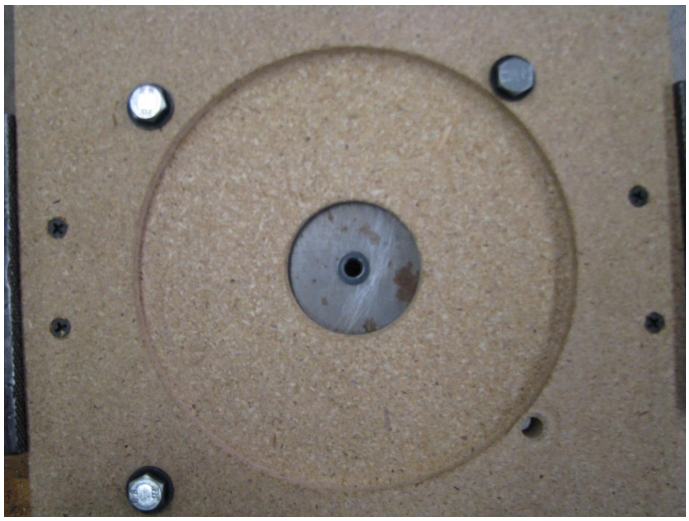

Figure 10. Base/Fixture of Prototype.

Parts (M) and (O) are the base top and bottom sections respectively. These parts correspond to the base/fixture on the prototype in Figure 10. These pieces act as the cam in the cam-follower style operation. The groove inside part (O) has a larger diameter than part (N) which allows the tool to move in a circular motion. Parts (M) and (O) guide the tool and allow the tool only 2 degrees of freedom to efficiently cut out the Rivnut® and reduce user error, by limited allowable movement.

Parts (P) and (S) are the neodymium ring and rod magnets respectively. The ring magnet centers on the Rivnut® and provides an outer surface to which the base can be located. The ring magnet is axially magnetized and has a pull of 75.62 Newtons. This magnet attracts the metal shavings as well as the threaded section of the Rivnut® to the backside of the sheet metal during the cutting process. The rod magnet is diametrically magnetized and has a pull of 20 Newtons. This magnet attracts the metal shavings the threaded section of the Rivnut® after the cutting operation. Part (P) is modified to be a lower profile magnet so the woodruff key seat cutter will be able to cut the Rivnut® without interference. Part (S) is slightly longer than the original rod magnet so it can be pressed into a handle to make it easier to remove the threaded end from the hole.

Figure 11. Rod Magnet and Ring Magnet.

Part (Q) is the woodruff key seat cutter. This is a metal cutting mill bit designed to cut slots/grooves in work-pieces. The woodruff key seat cutter has a shank diameter of 1/2 in., overall length of 2.0 in., cutter

diameter of 1/4 in., and a face width of 1/8 in. The cutter is designed to be used at an RPM of approximately 1681 based on manufacturer recommendation. The proposed face width on the woodruff key seat cutter is twice as thick as the prototype to fully remove the compressed ring.

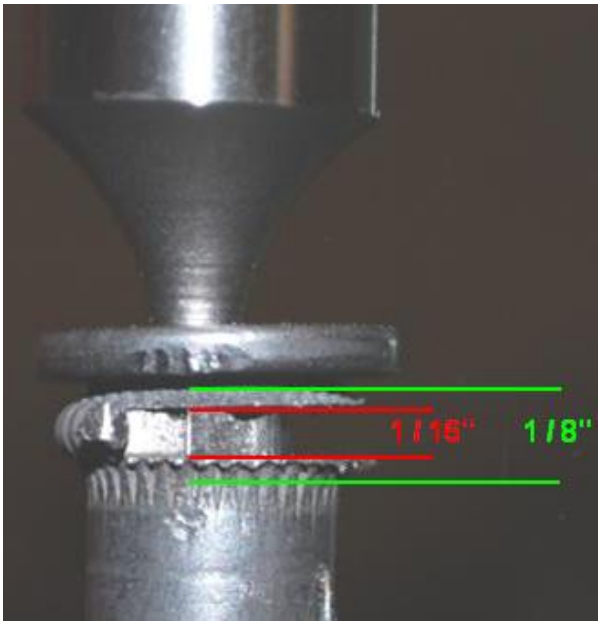

Figure 12. Woodruff Key Seat Cutter with Dimensions.

Parts (R) and (T) are the ring magnet remover and rod magnet handle respectively. The ring magnet remover is used to pull the ring magnet off of the sheet metal after the cutting process is complete. The rod magnet handle is used to make the process simpler and more ergonomic.

Parts (U) and (V) are drill bit letter "K", and drill bit letter "T". The "K" drill bit is used to remove threads from the Rivnut® to ensure the cutter is not limited axially before tool operation. The "T" drill bit is used to remove the head of the Rivnut® after the cutting process has been completed.

Figure 13. Type "K" Drill Bit.

Figure 14. Type "T" Drill Bit.

Parts (W) and (X) are static cling film and strong adhesive tape respectively. The static cling film is to be applied on the vehicle surface before any removal steps begin. This static cling film is to ensure the surface's integrity during the entire Rivnut® removal process. The strong adhesive tape is used to remove any shavings attracted to the magnets. The tape will allow the magnets to be reused for further Rivnut® removals without scratching the surface.

Each part in the recommended solution plays a key role in removing a Rivnut®. These components were based off of the original prototype. The complete prototype can be seen in Figure 15.

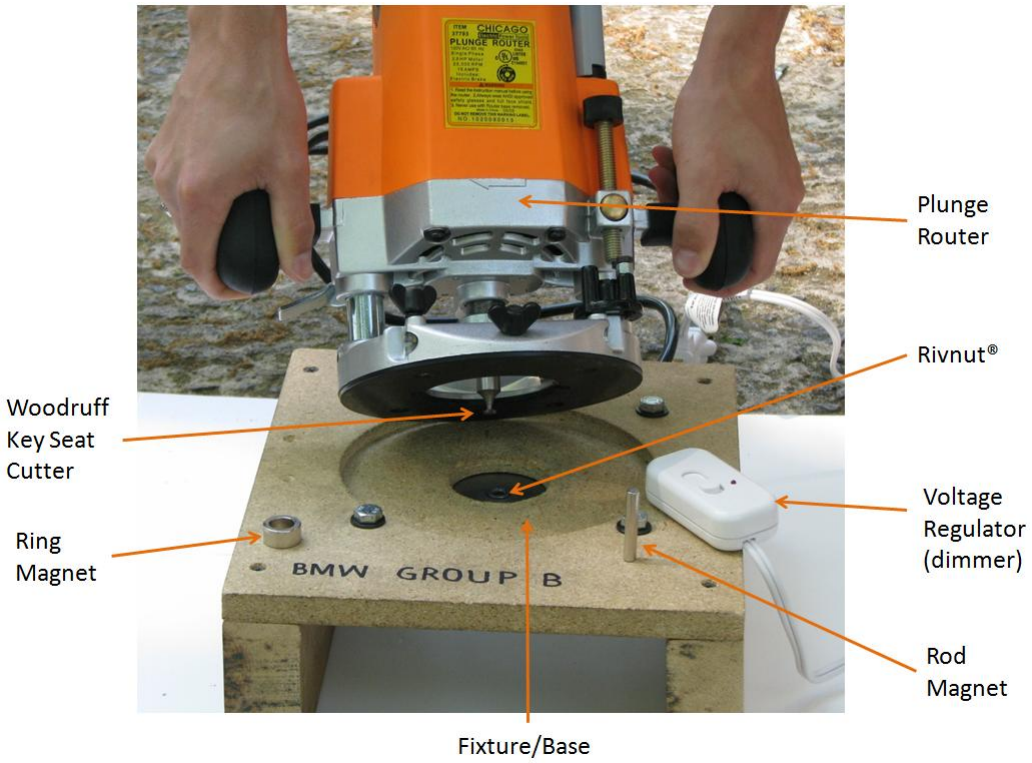

Figure 15. Labeled Prototype.

Verification of Design Solutions Against the Requirements

The two columns below compare the key aspects of the prototype and the recommended modifications made in the final design. The paragraph below these columns explains why these changes should be made.

Prototype	Recommended Design
• Woodruff key seat cutter has a 1/16” face width	• Woodruff key seat cutter has a 1/8” face width
• Uses a base that is (305 x 254 x 16) mm	• Uses a base that is 50.8 mm in diameter x 13 mm thick
• Total fixture weight is 7.23 kg	• Total fixture weight is 2.78 kg
• Device must use a dimmer switch to reduce motor output	• Motor designed to specific task - no step down of power is required
• Difficult to remove round magnet	• Includes round magnet removal tool

Figure 16. Prototype Picture.

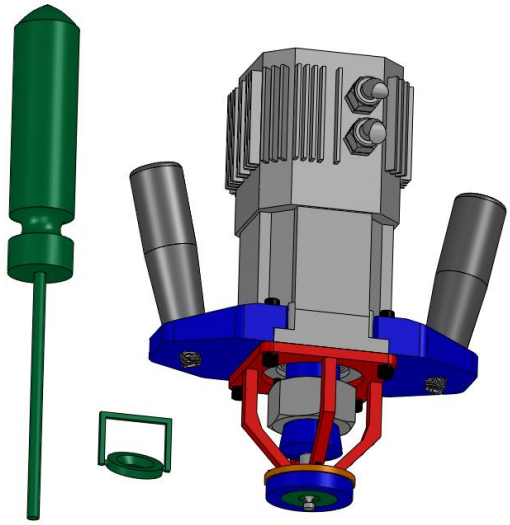

Figure 17. Recommended Solution.

The prototype design utilizes a woodruff key seat cutter with a 1/16" face width because this size was commercially available and inexpensive. The recommended design uses a 1/8" inch cutter face in order to complete the cutting operations in one pass. The recommended design uses a base that has a 50.8 mm diameter and fits in the flat area around a Rivnut® specified by BMW. Also, in reducing the size of the design, the total weight is reduced from 7.23 kg to 2.78 kg in the recommended design. A dimmer switch is required in the prototype design in order to reduce the motor output to an appropriate speed for the cutting operation, but in the recommended design, a motor designed for the specific task has been selected and does not need to be modified. To ease the removal of the ring magnet, a handle was incorporated in the final design concept.

The recommended design concept meets all of the constraints and most of the criteria for the project. The final design concept has a weight of 2.78 kg, which is below the set criteria of 4.5 kg. The process proposed in this report takes an average of 112 seconds. Final dimensions of the design concept are (27 x 23 x 10) cm which falls within the constraint values of (50.8 x 25.4 x 25.4) cm. The recommended design concept will remove a Rivnut® from a (5.08 x 5.08) cm flat surface. One constraint is that the final design must not alter base material in any way. A scratch test, seen in Appendix L, was performed which showed that the designed process would not scratch or alter the base material. OSHA safety (pinch points) and ergonomic constraints were considered in the design of the tool and process. Once set up for a specific size of Rivnut®, the process can be performed by the installer of the Rivnut®.

Two final design criteria that were not met in the recommended design concept were that the device should be able to remove Rivstuds® and that the design concept be available to the consumer at less than $500. The proposed design solution has a projected cost of $2211. This difference in price has resulted from half of the parts for the recommended design concept needing to be custom made. A more detailed view of the cost can be found in Appendix N.

The basic process of the recommended design concept was tested and proven to work using a prototype fixture as seen in Appendix L. The prototype fixture used a router which was turned down to an appropriate cutting speed using a dimmer switch. A motor with an appropriate RPM and torque was included in the recommended design concept. Also included in the design concept are magnets which are used to collect shavings and the threaded end of the Rivnut® after the cutting operation has been completed. Appendix J shows the magnet tests that were conducted in order to prove that using magnets is an acceptable way to collect and remove shavings.

APPENDIX A: BACKGROUND INFORMATION OF RIVNUTS®

Research of the Various Properties of Rivnuts®

Material, head size, thread type, and many other important features must be known in order to develop a tool/fixture that can accommodate an assortment of Rivnuts®. While BMW may only use a few different Rivnuts®, the ideal tool should be able to remove most, if not all, of the Rivnuts® researched. Figure 18 shows a variety of Rivnuts® as well as Rivstuds® provided by Böllhoff.

Figure 18. Common and Specialized Rivnut® and Rivstuds® by Böllhoff.[7]

The Rivnuts® are available in various materials such as: steel with zinc finish, steel, aluminum, and 430 stainless steel. The different Rivnut® materials are used for different applications that include sheet metal, tubing, and plastics. Knowing the material properties for both the Rivnuts® and the base material will help govern the design of the tool by determining the required tool material properties as well as the method chosen for removal.

The above Rivnuts® in Figure 18 have two different cross sections. The circular cross section is common for drilled or punched circular holes. In order to reduce spin-out, some contain a keyed head which fits into a slot in the hole. The hexagonal head is best suited for softer components (aluminum, plastics, etc.) and provides high turning resistance. The circular and hexagonal external geometries are implemented by BMW so it is important to study both and understand their applications.

Finally, the Rivnuts® are offered with varying size heads. As can be seen in Figure 19, the head has two different styles.

Figure 19. Flat Head (left) Rivnut® and Thin Head (right) Rivnut®.[7]

The flat head Rivnut® installs easily in punched or drilled holes and offers a larger surface area for easier installation. The thin head Rivnut® installs flush with the base material in order to allow a component to be mated to the base surface.

Rivstuds® are also used and serve the same basic function of securing a component to a base material that is only accessible from one side. Rivstuds®, however, are more commonly used in hanging applications where they are mounted on a vertical surface. Rivstuds® are offered only in metric threads and examples of Rivstuds® can be seen in Figure 20.

Figure 20. Rivstud® Examples.[7] *Steel with Zinc finish Rivstud® (left) and Un-worked/Worked Rivstud® (right).*

Installation Procedure and Installation Tools

Figure 21 below illustrates the basic principles of installing a Rivnut®. The first step is to drill a hole that is the same diameter as the outside diameter of the Rivnut®. BMW uses automated tools made by Gesipa® Fasteners USA to install the Rivnuts®. After the hole is drilled, the Rivnut® is threaded onto the threaded mandrel (the threaded shaft seen in step 1 of Figure 21 below). Next, the Rivnut® is inserted into the hole and the Rivnut® tool pulls the mandrel back into the tool. This effectively collapses the Rivnut® and now the mandrel spins in reverse to remove the mandrel from the Rivnut®. The Rivnut® is now ready to accept a bolt or screw.

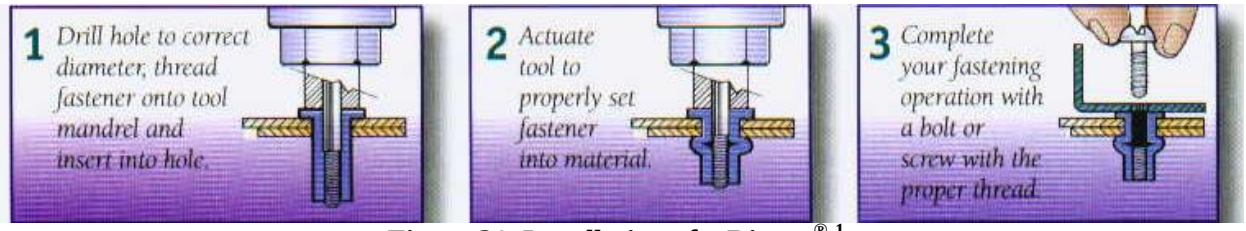
1 Drill hole to correct diameter, thread fastener onto tool mandrel and insert into hole.
2 Actuate tool to properly set fastener into material.
3 Complete your fastening operation with a bolt or screw with the proper thread.

Figure 21. Installation of a Rivnut®.[1]

Table 1 shows the specifications of the tools used by BMW to install Rivnuts® on vehicles. The most important specification of these tools to note is the traction power; this is the maximum amount of pulling force that the particular tool can use to collapse the Rivnut®. Additionally, it is important to note the diameters of Rivnuts® that these tools can install. This is shown in the far right column under work capacity in
Table 1. These specifications will be important when working on the problem of removing the damaged Rivnuts®.

Table 1. Specifications of Gesipa Rivnut® installer tools.[7]

Model	Mass	Operating Air Pressure	Working Stroke	Traction Power	Work Capacity
Pneumatic GBM 95	2.3 kg	586-793 kPa	Variable	15.7 kN	From 8-32 ø to 3/8-16 ø in all materials for thin wall type rivet nuts; up to 1/4-20 ø steel in thick wall type rivet nuts
12 Volt Cordless Firebird	2.2 kg	N.A.	Adjustable up to 5.5 mm	14.5 kN	6-32 ø to 5/16-18 ø Steel and Aluminum blind rivet nuts (3/8-16 ø Aluminum only)

Research on Current Rivnut® Removal Procedure

One downside of using Rivnuts® is the difficulty in removing them. The current process for removing damaged Rivnuts® involves three steps as seen in Figure 22. The first step as seen in the left side of Figure 22 is to drill through the head of the Rivnut®. The second step is to pry off the head of the Rivnut® as seen in the middle of Figure 22. The last step, seen on the right hand side of Figure 22, is to push out the shank of the Rivnut®.

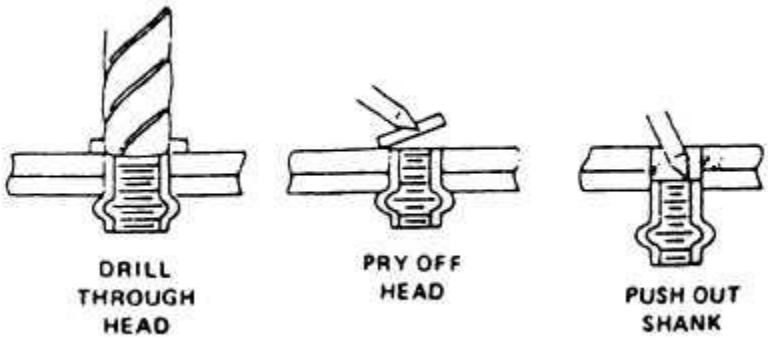

Figure 22. Removal of Rivnut®.[4]

The problem with this method is that when dealing with assembling vehicles, pushing out the shank of the Rivnut® leaves the shank inside the vehicle and is hard to remove. Any Rivnut® pieces that are left inside the vehicle will rattle while the vehicle is on the road, so the Rivnut® pieces must be removed entirely. The other option is to fill the compartment with foam so that the pieces do not rattle.

APPENDIX B: OSHA REGULATIONS

One of the constraints of the final design is that it must meet all of OSHA's safety (pinch points) and ergonomic constraints. These constraints are in place to save lives by preventing workplace injuries and illnesses. To ensure that the final design meets all the required regulations research was conducted to determine the exact conditions regarding these requirements.

Pinch Points

OSHA defines a pinch point as "…any point other than the point of operation at which it is possible for a part of the body to be caught between the moving parts of a press or auxiliary equipment, or between moving and stationary parts of a press or auxiliary equipment or between the material and moving part or parts of the press or auxiliary equipment." [8]

Therefore it is desired to eliminate any pinch points in the final design by redesigning the tool or fixture. If it is found that eliminating the pinch point is not feasible then guards should be designed and installed to protect the user from injury. Additionally, there must not be any pinch points created by the installation of the guard itself.

OSHA General Machine Requirements[8]

OSHA has general requirements that all machines and their respective guards have to meet. These are outline below.

OSHA Standard Number: 1910.212
Subpart Title: Machinery and Machine Guarding
Title: General Requirements for All Machines

1910.212(a)(1)

> Types of guarding. One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks. Examples of guarding methods are-barrier guards, two-hand tripping devices, electronic safety devices, etc.

1910.212(a)(2)

> General requirements for machine guards. Guards shall be affixed to the machine where possible and secured elsewhere if for any reason attachment to the machine is not possible. The guard shall be such that it does not offer an accident hazard in itself.

1910.212(a)(3)(i)

> Point of operation is the area on a machine where work is actually performed upon the material being processed.

1910.212(a)(3)(ii)

> The point of operation of machines whose operation exposes an employee to injury, shall be guarded. The guarding device shall be in conformity with any appropriate standards therefore, or, in the absence of applicable specific standards, shall be so designed and constructed as to prevent the operator from having any part of his body in the danger zone during the operating cycle.

1910.212(a)(3)(iii)

Special hand tools for placing and removing material shall be such as to permit easy handling of material without the operator placing a hand in the danger zone. Such tools shall not be in lieu of other guarding required by this section, but can only be used to supplement protection provided.

OSHA Hand-Held Tool Requirements[8]

Since the final design will probably be a hand-held tool the regulations that may apply are listed below.

OSHA Standard Number: 1910.243
Subpart Title: Hand and Portable Powered Tools and Other Hand-Held Equipment
Title: Guarding of Portable Powered Tools

1910.243(a)(2)(ii)

All hand-held powered drills, tappers, fastener drivers, horizontal, vertical, and angle grinders with wheels greater than 2 inches in diameter, disc sanders with discs greater than 2 inches in diameter, belt sanders, reciprocating saws, saber, scroll, and jig saws with blade shanks greater than a nominal one-fourth inch, and other similarly operating powered tools shall be equipped with a constant pressure switch or control, and may have a lock-on control provided that turnoff can be accomplished by a single motion of the same finger or fingers that turn it on.

1910.243(a)(2)(iv)

The operating control on hand-held power tools shall be so located as to minimize the possibility of its accidental operation, if such accidental operation would constitute a hazard to employees.

OSHA Cutting Tools Requirements[8]

In the case that the final design utilizes a cutting procedure the OSHA regulations that apply to this project are listed below.

OSHA Standard Number: 1910.252
Subpart Title: Welding, Cutting, and Brazing
Title: General Requirements

1910.252(a)(2)(xiii)

Management. Management shall recognize its responsibility for the safe usage of cutting and welding equipment on its property and:

1910.252(a)(2)(xiii)(A)

Based on fire potentials of plant facilities, establish areas for cutting and welding, and establish procedures for cutting and welding, in other areas.

1910.252(a)(2)(xiii)(B)

Designate an individual responsible for authorizing cutting and welding operations in areas not specifically designed for such processes.

1910.252(a)(2)(xiii)(C)

Insist that cutters or welders and their supervisors are suitably trained in the safe operation of their equipment and the safe use of the process.

1910.252(a)(2)(xiv)(E)

Shall determine that the cutter or welder secures his approval that conditions are safe before going ahead.

APPENDIX C: ANALYTICAL ANALYSIS OF COLLAPSING RIVNUTS®

Summary

A preliminary stress analysis was performed on a Rivnut® to determine approximately how much force is required to compress a Rivnut®. Measurements were taken using vernier calipers. These measurements were used to create a CAD model and to do an analysis on how much force it takes to yield a Rivnut®. Since the type of steel was unknown, many types of steel and aluminum were analyzed and averaged. The theoretical force it takes to collapse a Rivnut® is 3843 N.

Calculations

Using a set of vernier calipers, Rivnut® measurements were taken and recorded. These values were then used to generate a CAD (Computer Aided Design) model. The model was used to better understand the geometry of the Rivnuts® and get a perspective of how the cross-section varied throughout the Rivnut® length without having to cut into one of the provided Rivnuts®. The CAD model may also be used for FEA (Finite Element Analysis) if more stress information is required after the preliminary analysis. Refer to Figure 23 for a preliminary detailed drawing.

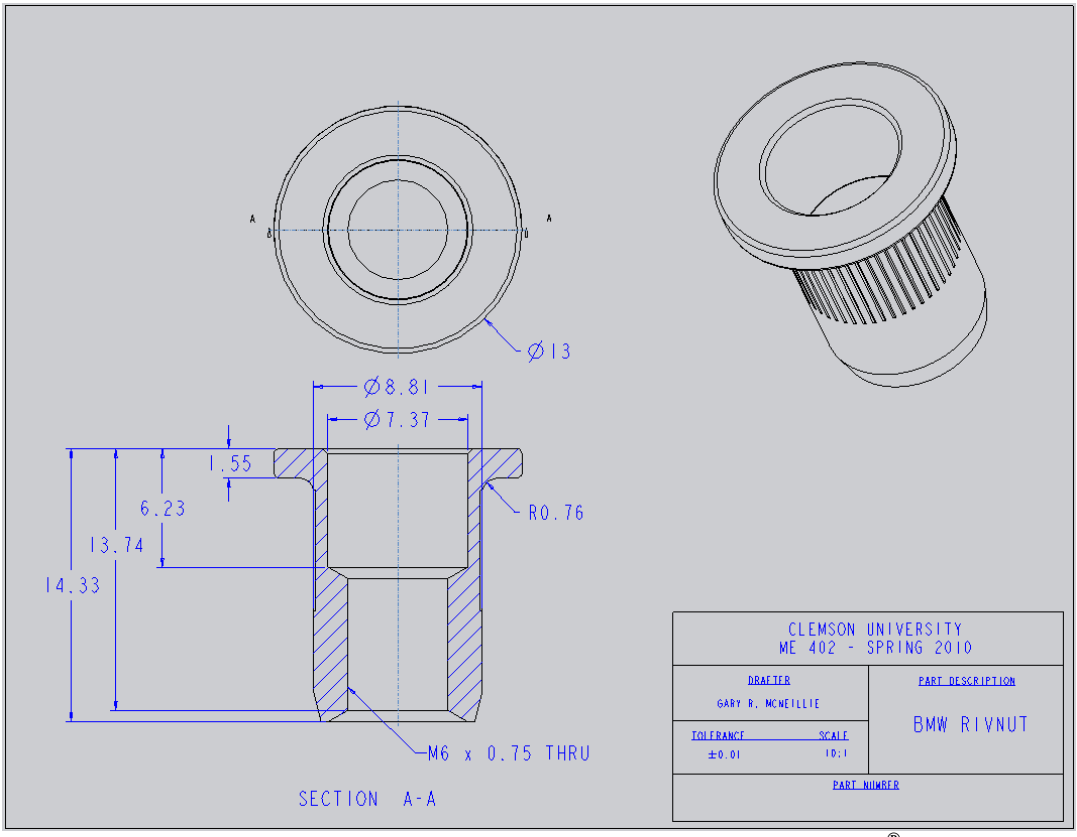

Figure 23. Preliminary CAD Drawing for Böllhoff Rivnut®.

Using superposition, the applied load over the entire Rivnut® could be modeled as a load acting axially on a cylinder with inside and outside diameters matching the thinnest cross-section of the Rivnut®. This method should give an approximate value for the required deformation load. See Figure 24 for reference.

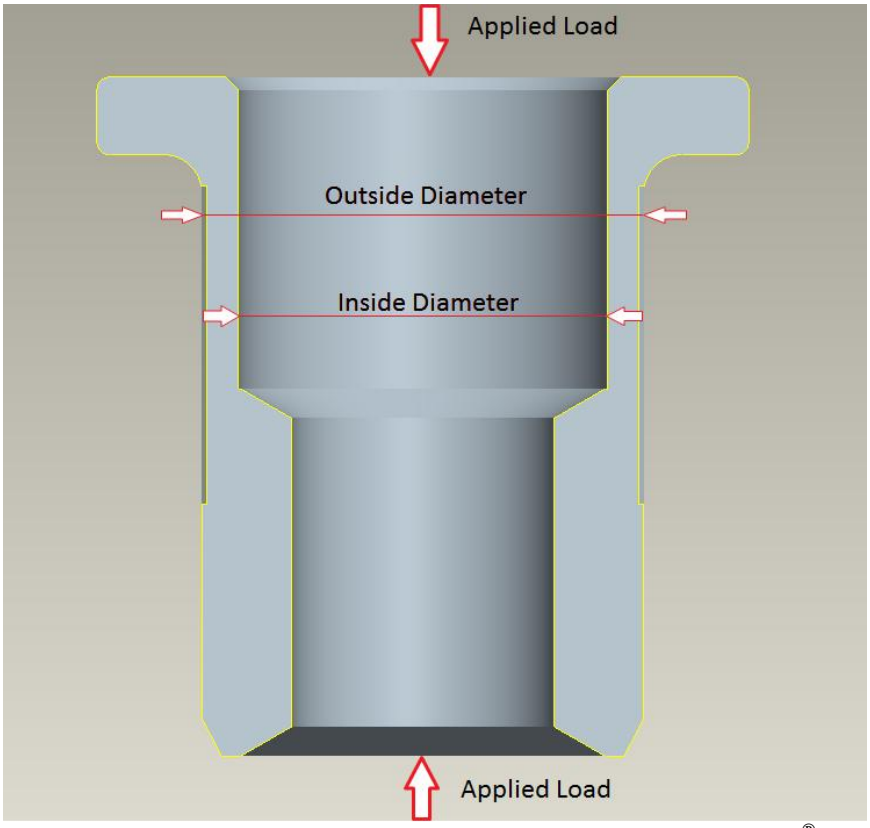

Figure 24. Stress Acting on Cylindrical Section of the Rivnut®.

The load acting on the Rivnut® is purely uni-axial due to the Rivnut® design and the installation tool. Using the equation for stress seen in Eq. (1), the required deformation force could be found.

$$\sigma = \frac{F}{A} \tag{1}$$

Where σ is the yield strength of the material, F is the required deformation force, and A is the effective cross-sectional area. Table 2 shows the measured Rivnut® dimensions used for the stress/force analysis.

Table 2. Rivnut® Dimensions.

Inside Diameter (mm)	Outside Diameter (mm)	Effective Area (mm^2)
7.34	8.81	0.71

Using the values in Table 2 and the stress formula from Eq. (1), the required deformation forces could be obtained for the Rivnut® material.

The material of the Rivnuts® was given in the catalog provided by Böllhoff. These properties were then looked up and put into Table 3.

Table 3. Required theoretical deformation force of Actual Rivnut®.

Material	Yield Strength (Pa)	Force to Yield Rivnut (N)
Steel (C1010-1008)	$3.05e^{8}$	5521

APPENDIX D: EXPERIEMENTAL ANALYSIS OF COLLAPSING AND UN-COLLAPSING RIVNUTS®

Summary

To aid in developing some solutions to the problem of removing a Rivnut®, it was first necessary to determine some characteristics about the Rivnuts® themselves. Three experiments were conducted to determine some of the key characteristics of the Rivnuts®. The first was to determine the compressive force required to collapse the Rivnut® so that it was installed properly on the base material. This experiment was conducted with the Rivnut® collapsing onto sheet metal, as to accurately model the force required to install the Rivnut®. The second experiment was similar to the first but the Rivnut® was collapsed without the sheet metal. For the last experiment it was desired to determine the required force necessary to un-collapse the Rivnut® once it was installed in sheet metal.

The experimental results showed that it took 6654 N of force to compress the Rivnut® on sheet metal and 6486 N of force to compress the Rivnut® without sheet metal. The next test showed that it took 7824 N of force to un-collapse a Rivnut®; however, the Rivnut® did not stretch back out completely. The Rivnut® instead broke into two pieces before being fully restored. Also, when the Rivnut® was heated, it did not produce different results.

Experimental Setup

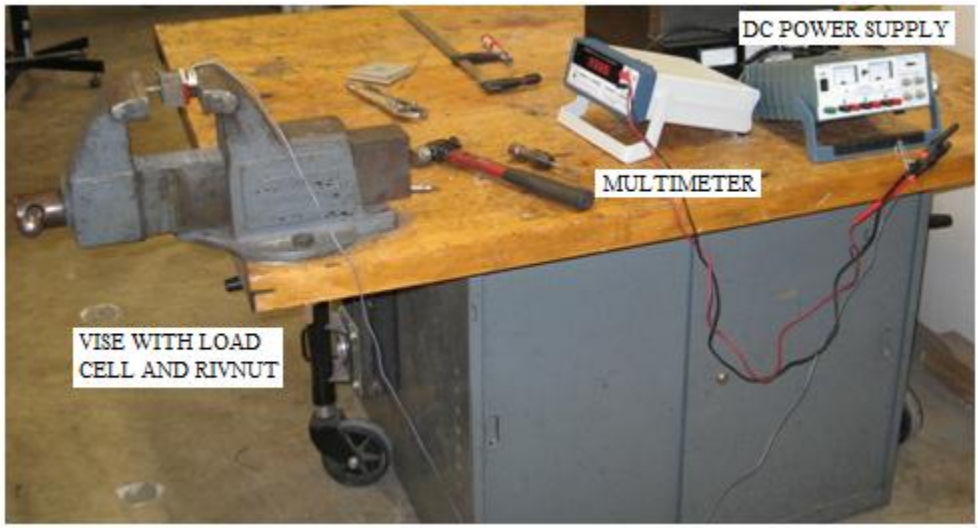

Figure 25. Experimental Setup.

Figure 25 shows the setup of the experiment. A vise was used to supply the force to collapse the Rivnut®. A calibrated load cell, with a max load capacity of 8896 N, was used to measure the force exerted on the Rivnut®. This load cell was powered by a 10 volt DC power supply. A digital multi-meter was used to read the output of the load cell.

Compression

In the first experiment, the apparatus was set up as shown in Figure 26. The load cell was position to read the force required to compress the Rivnut® onto the sheet metal. Once this test was completed then the second test was performed. This test was set up identical to Figure 26 but now the sheet metal was removed.

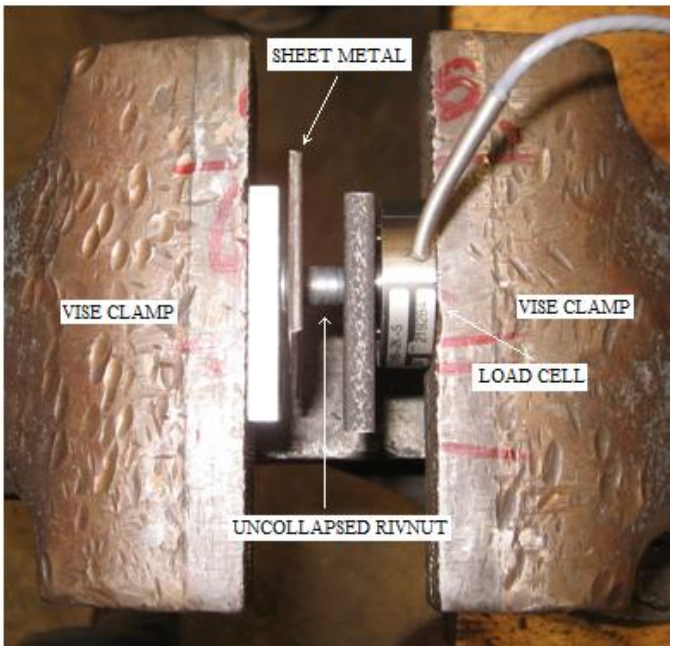

Figure 26. Compression Test Setup.

Tension

For the final test, the apparatus was set up a little different. As can be seen in Figure 27 the Rivnut® was collapsed onto the sheet metal and a bolt was installed into the Rivnut®.

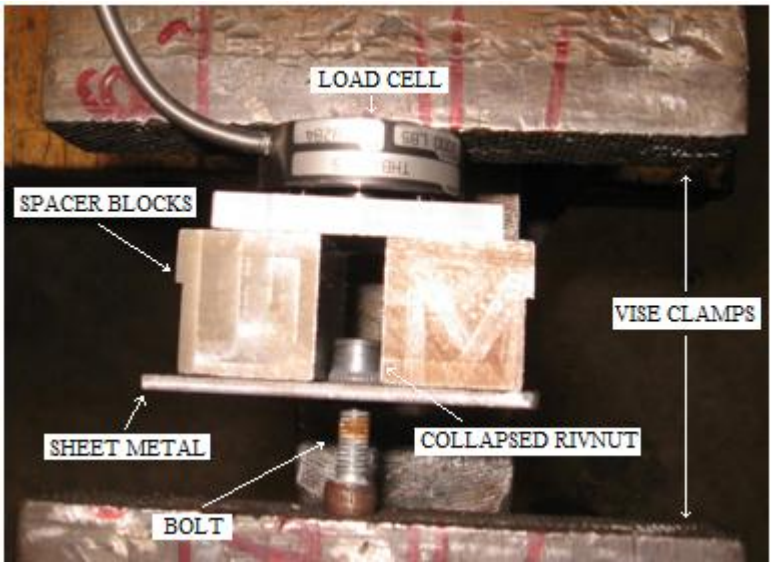

Figure 27. Tension Test Setup.

As the vise was tightened the bolt pushed against the threads inside the Rivnut® and caused the Rivnut® to elongate. With the spacers shown the load cell was positioned to read the required force that the Rivnut® needed to return to its uninstalled condition.

Calibration

Before using the load cell, the group calibrated it. This was performed by having each group member weigh themselves on a scale. Next they stood on the load cell and the output of the load cell was recorded. After performing this calibration it was compared to a calibration performed by the manufacturer in 2008. It was found that the calibrations were within 3% of each other. Figure 28 shows both the curve from the manufacturer's calibration in 2008 and the calibration performed for this experiment in 2010. Because the calibration was performed on a range of (0-1157) Newtons, it was decided that this calibration was unacceptable because we were tested in a range much higher than 1157 Newtons.

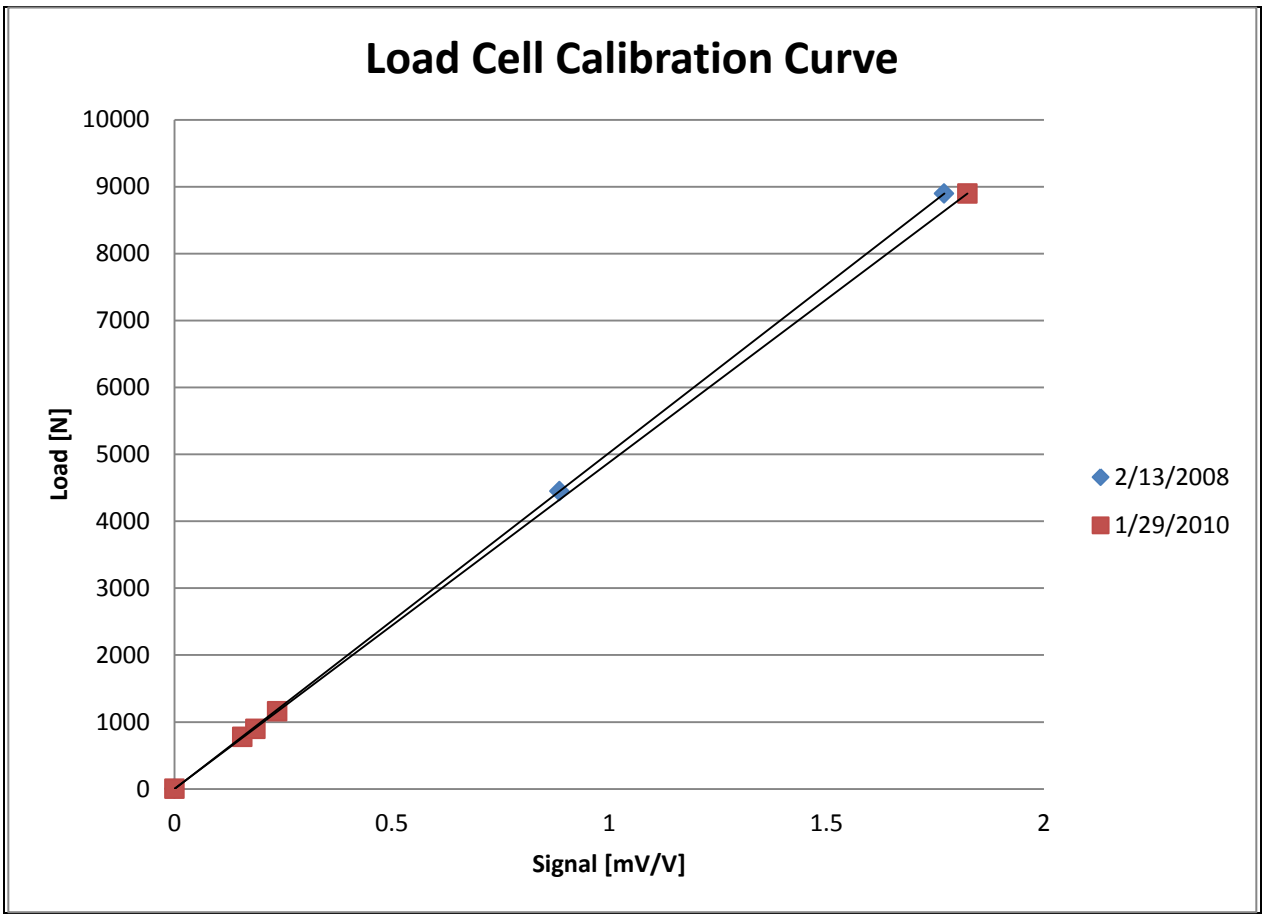

Figure 28. Load Cell Calibration Curves.

Procedure

Once the test was set up, two group members performed the experiments. Below are the steps used to conduct the experiment so that uniformity was maintained.

1. Ensure the load cell, spacers, Rivnut®, bolt, andsheet metal are in line between the vise clamps
2. One group member began very slowly to tighten the vise in a smooth uniform fashion

3. The other group member monitored the reading on the multi-meter as well as the condition of the Rivnut®
4. Once the Rivnut® was either collapsed or elongated to the desired amount the reading on the multi-meter was recorded
5. Repeat steps 1 – 4 the desired number of times

Results

Table 4 shows the results of the compression test. In this test the sheet metal was not present. It was found that it takes a load of approximately 6655 N to install a Rivnut® onto a piece of sheet metal.

Table 4. Compression Results.

Compression With Sheet Metal		
Test Number	Output [mV/V]	Load [N]
1	1.34	6534
2	1.39	6779
3	1.35	6583
4	1.38	6730
Average Load	N/A	6655

Table 5 shows the result that it takes approximately 6655 N of force to collapse a Rivnut®, with no sheet metal present. This force is 97.43% of the force required to collapse the Rivnut® onto a piece of sheet metal as seen in Table 5.

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Table 5. Compression Results without Sheet Metal.

Compression Without Sheet Metal		
Test Number	Output [mV/V]	Load [N]
1	1.31	6388
2	1.37	6681
3	1.35	6583
4	1.29	6290
Average Load	N/A	6486

The last test to determine the force required to elongate the Rivnut® yielded some unexpected results. Instead of stretching the Rivnut®, the Rivnut® actually reached its tensile strength and broke. Figure 29 shows how the Rivnut® broke into two pieces. Instead of stretching out the already yielded material, the material between the sheet metal and the bolt failed.

Figure 29. Tension Test Results.

Table 6 shows that at a force of approximately 7824 N, the Rivnut® yielded and then subsequently broke in half.

Table 6. Tension Results.

Tension		
Test Number	Output [mV/V]	Load [N]
1	1.65	8047
2	1.61	7851
3	1.55	7558
4	1.61	7851
Average Load	N/S	7826

This result was very interesting because most of the concepts that the group had been considering required that the Rivnut® not break under this type of load. To possibly remedy this problem the Rivnut® was heated up for one minute by a propane torch and then the tension test was performed. The same results were obtained. Then the Rivnut® was heated for two minutes, which is the maximum time allowed to remove the Rivnut®, again the same results were found. Therefore heating up the Rivnut® has no effect on enabling it to elongate before breaking into two sections while keeping the time constraints.

APPENDIX E: MODIFICATION OF RIVNUTS®

Summary

One idea that was explored during the concept phase of tool/fixture development was to modify an existing Rivnut® to see if any minor changes would allow for easier removal. By making small changes to the geometry, the Rivnut® may yield in critical areas instead of breaking, thus making complete removal possible. The two tests that were completed were the hole drilling test and the turn-down test.

The turning down method reduced the cross-sectional area of the critical section of the Rivnut® by use of a lathe. The hole drilling method placed small holes in the critical section of the Rivnut® to weaken it and allow for yielding instead of breaking before and after the compression ring.

Both methods were then tested in a tension test, as in Appendix D, to see if yielding would occur instead of breaking. The turn-down test yielded one successful removal of a Rivnut® while the hole drilling test only flared out the Rivnut®, making the problem worse, where it was drilled. After speaking with BMW, it was discovered that modifying the Rivnut® was not an option so these tests were not further explored.

Experimental Setup

Turn-Down

Figure 30. Turned-Down Rivnut® on Lathe.

Figure 30 shows a Rivnut® that has been turned down on a lathe. The Rivnut® was inserted into the chuck on a lathe and a cutting tool was used to remove material from the outside of the Rivnut®. Arbitrary amounts were removed for three different Rivnuts® and the values were recorded before testing was performed. Table 7 consists of turn-down test parameters.

Table 7. Turn-Down Test Dimensions.

Test Number	Original Diameter (mm)	Turn-Down Diameter (mm)	Diameter Reduction (mm)
1	8.81	8.43	0.38
2	8.81	8.38	0.43
3	8.81	8.08	0.74

Hole Drilling

Figure 31. Hole Drilling Rivnut®.

Figure 31 shows a Rivnut® installed in a small vise being drilled on a drill press. Holes were drilled in the Rivnut® at various distances from the head/flange and in different quantities as well as ranging drill bit sizes. Table 8 consists of hole drilling test values.

Table 8. Hole Drilling Test Parameters.

Test Number	Bit Diameter (mm)	Number of Holes	Distance from Flange (mm)
1	1.78	4	5.38
2	2.39	4	4.90
3	1.98	3	5.46
4	1.32	3	5.72

Procedure

Turn-Down

The Rivnut Turn-Down Test procedure consists of the following steps:

1. Mount the Rivnut® in the chuck of a machining lathe
2. Attach a cutting tool to the 2-axis tool post
3. Power on lathe and set to desired rpm
4. Move cutting tool post to desired starting axial location on Rivnut®
5. Move cutting tool post to desired radial location on Rivnut® to begin cutting
6. Slowly advance axially until desired amount of material is removed from the outside diameter of the Rivnut®
7. Relocate tool post to a safe location on the lathe machine away from work piece
8. Power off lathe and remove Rivnut®
9. Repeat steps until all Rivnuts® have been modified

Hole Drilling

The Rivnut® Hole Drilling Test procedure consists of the following steps:

1. Secure a Rivnut® in a small vise
2. Insert the desired drill bit size into the drill press
3. Locate the vise on the drill press platform the desired distance from the Rivnut® flange and centered radially on the Rivnut®
4. Power on the drill press and advance the bit towards the work piece until a hole has been made
5. Back the drill bit out and power off the drill press
6. Loosen the vise and rotate the Rivnut® to the next desired location
7. Repeat steps 1-6 until desired number of holes have been drilled

Results

Turn-Down Test

Once all of the Rivnuts® had been turned down to different diameters, they were compressed around a piece of sheet metal and then an axial load was placed on them to stretch them back out. Upon observation during the stretching process, Specimens #1 and #2 only stretched slightly until ultimately breaking. Upon observation of specimen #3, the Rivnut® expanded significantly and appeared as if it could be pulled through the base-material hole. Tolerances were very tight so more load was applied and the specimen broke. Upon failure, the specimen was able to be completely removed without damaging the base material. Figure 32 shows the successful modified Rivnut®.

Figure 32. Turn Down Test Specimen #3.

While the Rivnut® had been completely removed, it had been altered from its original geometry which is not how the Rivnut® was supplied. The team believes that if the Rivnuts® could be designed with a thinner critical wall thickness then the Rivnuts® could still potentially hold a certain load but also have the capability of being removed from the base material. Further testing is required to determine the load carrying capacity of a turned-down Rivnut®.

Hole Drilling Test

Once the holes had been drilled into all of the Rivnuts®, they were compressed in a piece of sheet metal as can be seen in Figure 33.

Figure 33. Hole Drilling Test Specimen #2 Compressed in Sheet Metal.

Each specimen was then loaded axially to stretch them back to the original geometry. Upon observation, all specimens stretched and broke at the locations of the holes. These results were expected and while the deformed compression ring area had been stretched back out a significant amount, the break at the holes caused another issue. The places where the holes were drilled flared when the Rivnuts® were compressed, but upon stretching they remained close to the same shape. Figure 34 shows a specimen that was nearly able to be removed because of the reduction of the deformation ring, but remained in the hole due to the drilled holes flaring.

Figure 34. Hole Drilling Result with Flared Edges.

None of the hole drilling test specimens were able to be removed from the sheet metal without either extreme force or methods that would damage the base material. It should also be noted that the threaded section would not come through the hole in any of the hole drilling cases.

It would be worthwhile to perform more tests using the Turn-Down method to ensure that the results of Specimen #3 could be repeated. Load carrying capacity tests need to be performed as well to ensure the Rivnut® still performs its intended job. Hole drilling in the Rivnut® has proven to be an unsuccessful route for modification and removal.

APPENDIX F: BORE CUTTING TEST

Some of the concepts that are being considered require that the compressed ring of material on the Rivnut® be removed by some type of cutting or grinding process. A simple experiment was conducted to determine the feasibility of this concept.

Experimental Setup

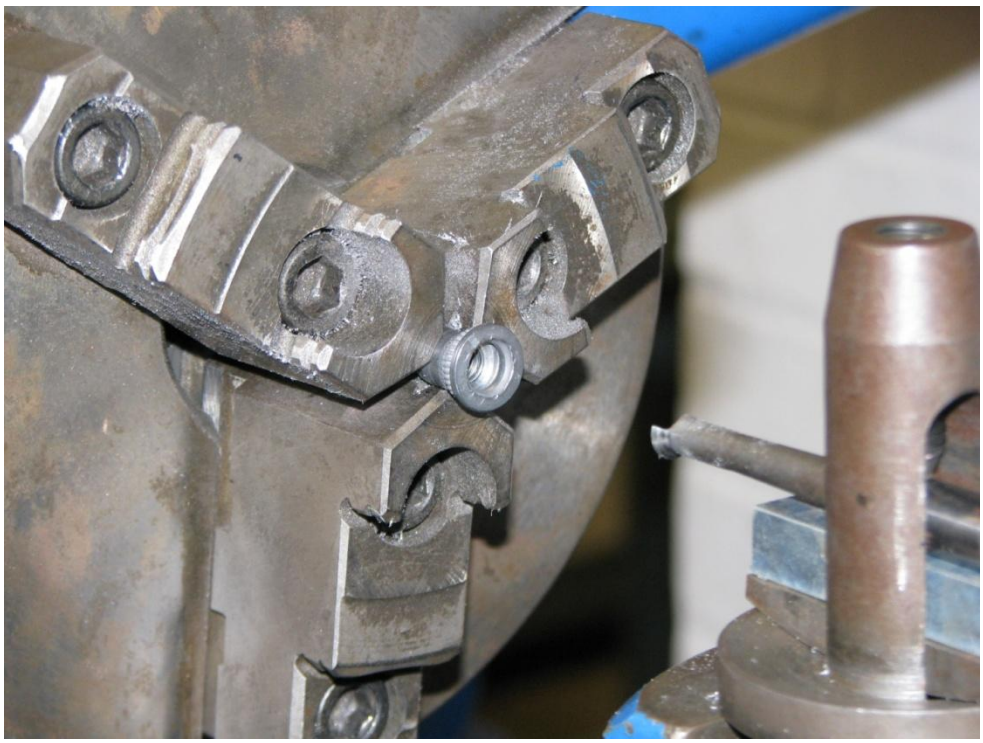


Figure 35. Experimental Setup.

Figure 35 shows the setup of the experiment. The Rivnut® was secured in the rotating end of a lathe. A bore cutting tool was fixed so that it could enter the center of the Rivnut®.

Procedure

The procedure that was followed to conduct this experiment is as follows:

1. Fix the Rivnut® in the rotating end of the lathe
2. Fix the bore cutting bit in the other end of the lathe so that it properly aligns with the center of the Rivnut®
3. Start the lathe
4. Move the bore cutting bit into the Rivnut® slowly until the blade is aligned inside with the compressed ring of material
5. Horizontally move the bore cutting bit slowly until the Rivnut® is completely cut into two pieces, as in Figure 36

6. Turn off the lathe
7. Repeat as desired

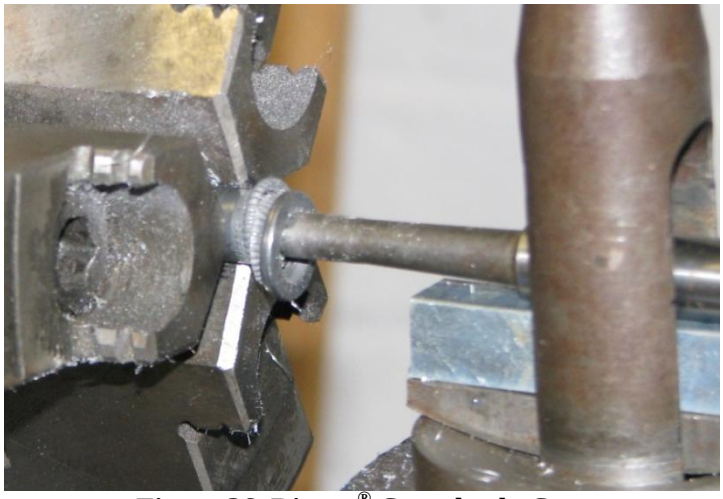


Figure 36. Rivnut® Completely Cut.

Results

Two Rivnuts® were tested in this way. The first Rivnut® was cut immediately after the compressed material. Figure 37 show the result of this test.

Figure 37. 1st Bore Cut Rivnut®.

The next Rivnut® was cut directly in the center of the compressed ring which can be seen in Figure 38.

Figure 38. 2nd Bore Cut Rivnut®.

In conclusion, it was found that cutting Rivnuts® in this manner is possible; however, a different type of cutting operation will have to be used such as a grinding wheel that could completely remove the compressed ring**.**

APPENDIX G: RING COMPRESSION TEST

Summary

Some of the potential designs being considered leave behind a ring of material that is larger in diameter than the hole the Rivnut® was installed. This ring of material must be removed from inside the body; therefore, a test was performed to determine the force required to compress this ring enough to remove it from the hole the Rivnut® was installed.

It was determined that the force required to compress this ring enough to remove it from the hole the Rivnut® was in is 489 N. To quantify this force, another test was done to determine how much force a person could apply to the ring with one hand and a pair of pliers. This force was found to be approximately 1139 N.

Experimental Setup

The rings were cut from collapsed Rivnuts® using a rotary cutting tool. Figure 39 shows the three test rings before compression.

Figure 39. Rivnut® Rings.

Once these rings were obtained, a vise, as can be seen in Figure 40 was used to compress these rings. A load cell was used to measure the force required to compress the rings.

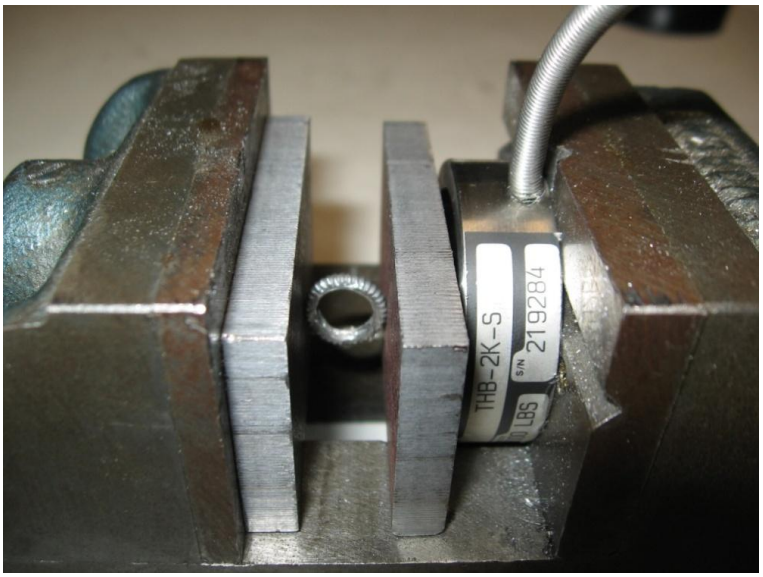


Figure 40. Experimental Setup.

Procedure

One member of the team monitored the reading from the load cell while one member slowly and smoothly compressed the Rivnut® with the vise. Once the ring was sufficiently compressed enough to allow it to be removed from the Rivnut® hole, the load cell reading was recorded. Additionally, a second test was performed for comparison. In this test one group member used one hand to apply a compressive load to the load cell via a pair of standard pliers. This test was performed only to allow the group members to get a better understanding of the amount of force required to compress the ring compared to the amount of force that a person can apply using only a pair of pliers.

Results

Figure 41 shows the rings after the test was performed. These rings can now pass through the hole that the Rivnut® was installed in.

Figure 41. Compressed Rings.

Table 9 shows the average load required to compress one of these rings and Table 10 shows the force an average person, using one hand, can compress with using only a standard pair of pliers.

Table 9. Ring Compression Load.

Ring Compression Test	
Output [mV/V]	Load [N]
0.1	489
0.1	489
0.1	489
Average	489

Table 10. Compressive Load from Pliers.

Standard Pliers Compression	
Output [mV/V]	Load [N]
0.2	979
0.2	979
0.3	1463
Average	**1139**

Therefore, the ring can be compressed using only 43% of a person's strength using standard pliers. It must be noted that this ring must be compressed while inside the hole that the Rivnut® was installed in,

because this is the only access point to the ring. It is possible to compress this ring but a special tool must be made to fit in the confined space.

APPENDIX H: SHAVINGS TEST

One of the constraints that BMW set was that no shavings from the Rivnut® can be left inside the body. If the final design consists of a cutting operation, then inevitably, there will be shavings. It was decided that these shavings needed to be quantified. Two different tests were performed. In the first, a hack saw was used to make two parallel cuts in a Rivnut®. The shavings from this test were then collected and weighed. The second test was performed to determine the percentage of shavings that would exit the Rivnut® through the threaded end compared to the shavings exiting the flange end when the Rivnut® was drilled.

Experimental Setup

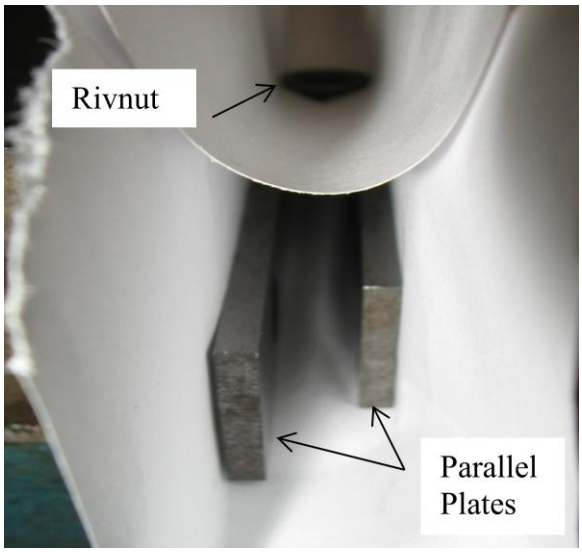


Figure 42. Experimental Setup.

Drill Test

Figure 42 above shows the setup of the experiment. Paper was put into a vise to catch any shavings that fell through the threaded end of the Rivnut®. Parallel plates were put on top of the paper to hold the sheet metal that held the Rivnut® in place while drilling occurred. A hole the size of the Rivnut® was punctured into another piece of paper in order to catch any shavings that exited the flange end, and a Rivnut® was placed into the hole in the paper. The same test was performed, but this time the Rivnut® was plugged at the threaded end with a bolt.

Hacksaw Test

For this test, a similar setup was used as in Figure 42. Paper was put into a vise to catch any metal shaving from the Rivnut®. The Rivnut® was then clamped with the vise orientated so that the hole in the Rivnut® was horizontal.

Procedure

After the experiment was set up, the following procedures were used.

Drill Test

1. Ensure that the sheet metal the Rivnut® is set into is clamped into the vise and unable to move
2. Line up the middle of the Rivnut® with a 0.909 cm diameter drill bit on the drill press
3. Plunge the drill bit into the Rivnut® slowly, letting chips go to their respective areas, until the Rivnut® has been removed
4. Carefully remove the top paper with the Rivnut® top and shavings, and place the shavings in a bag
5. Carefully remove the bottom paper with the shavings, and place the shavings in a bag
6. Weigh both the top and bottom portion shavings

Hacksaw Test

1. Ensure that the Rivnut® is clamped into the vise and unable to move
2. Place the hacksaw in the middle of the clamped Rivnut®
3. Very slowly move the hacksaw to make a small grove on the Rivnut® for the hacksaw blade to rest
4. Keep working the hacksaw until the Rivnut® is completely cut on that side
5. Unclamp the Rivnut®, rotate 90º, and re-clamp being very careful not to deform the Rivnut®
6. Repeat steps 2-4
7. Carefully remove the Rivnut® and the piece of the Rivnut® that was cut. Remove the paper and place the shavings in a bag
8. Weigh the shavings

Results

Table 11 shows the mass and percentage of the shavings from the drill test.

Table 11. Drill Test Results.

End of Rivnut®	Mass (g)	Percentage of Total Weight
Flange	0.311	78.3%
Threaded	0.086	21.7%

After this test was performed, a similar test was done with a bolt to enclose the bottom portion of the Rivnut®. The same procedure was followed as before and the vast majority of the shavings came out of the top as can be seen in Figure 43 below.

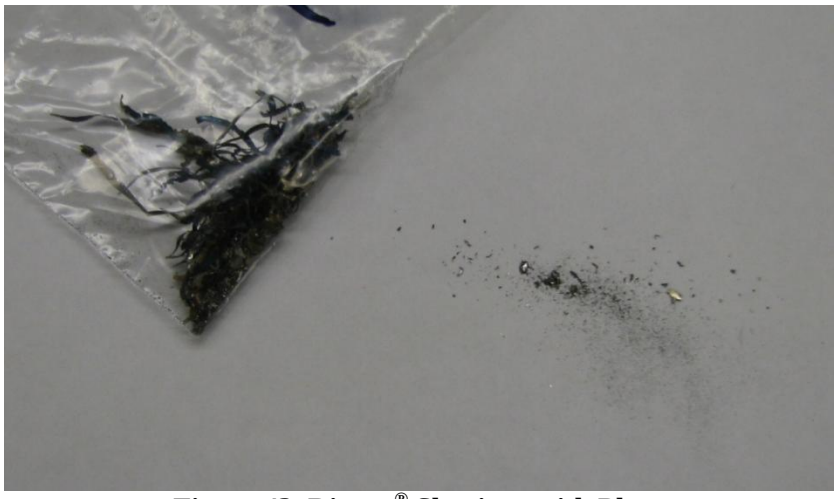


Figure 43. Rivnut® Shavings with Plug.

The shavings that are in the bag are the shavings that came out the top of the Rivnut® and the shavings that are outside the bag are the ones that were left in the Rivnut®.

Table 12 shows the weight of the material shaved off from the hacksaw test.

Table 12. Hacksaw Test.

Part	Weight (g)
Shavings	0.27

To understand how little the shavings weigh, several Rivnuts® were weighed and are shown below in Table 13.

Table 13. Mass of Rivnut®.

Rivnut®	Mass (g)
1	3.74
2	3.72
3	3.72
4	3.72
5	3.76
6	3.73
Average	3.73

As one can see, the weight of the shavings was very small when compared to the overall weight of the Rivnut®. Another important note is that the shavings that were collected were as fine as dust. This, as well as the size of the piece removed, can be seen in Figure 44 below.

Figure 44. Rivnut® Pieces from Hacksaw Test.

The drill test results showed that when the Rivnut® was drilled out, more shavings came out the flange end; however, some shavings did exit though the threaded end. When the Rivnut® was plugged, almost no shavings were left in the Rivnut® and most of the shavings came out the flange end, as one would suspect. The hacksaw test results showed that only a small amount of shavings were made from sawing the Rivnut®. Also, these shavings were very small when compared to the shavings from the drill test.

APPENDIX I: MATERIAL REMOVAL STRETCH TEST

Summary

One idea that was tested was whether it is possible to adequately remove material from the inside of the Rivnut® that would allow the Rivnut® to be stretched enough to remove it from the hole. There were two methods to test this theory. One was to remove material from the critical yielded area once the Rivnut® was already installed using a rotary cutting tool. The other was to remove material from the inside diameter of the Rivnut®, at the critical yielding area, using a lathe. Both methods tested to see if, once this material has been removed, the Rivnut® could be then stretched in tension and removed.

Both tests showed that when material is removed either before or after installation, the Rivnut® cannot be stretched to be removed.

Experimental Setup

This first experiment was set up as in Figure 45. With the Rivnut® installed in sheet metal it was clamped in a vise for stability. The rotary cutting tool was used to remove material from the compressed ring.

Figure 45. Rotary Tool Material Removal Setup.

The second experiment was set up as in Figure 46. A small cutting tool was used to remove material from the inside of the Rivnut®. The Rivnut® was fixed in the rotating side of the lathe.

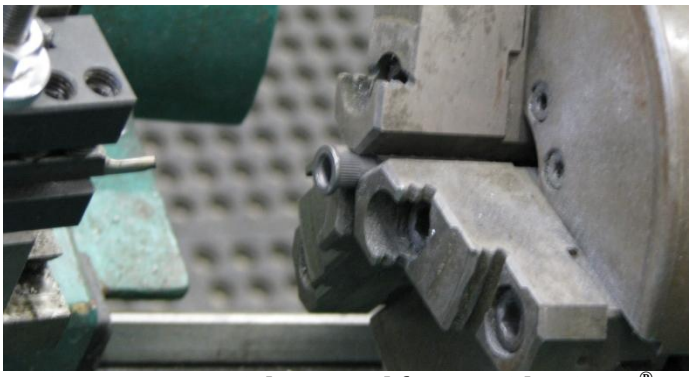


Figure 46. Material Removal from Inside Rivnut®.

Procedure

Rotary Tool Procedure

1. Install Rivnut® in sheet metal
2. Using the diamond tipped cutting tool remove material from inside the Rivnut®
3. Conduct the tension test to determine if Rivnut® can be removed

Note: The cutting tool lasted only long enough to complete one Rivnut®

Lathe Material Remove Procedure

1. Set up experiment as shown in Figure 46
2. Engage the cutting tool in the inside of the Rivnut®
3. Once the desire amount of material is removed the cutting tool should be removed
4. Conduct the tension test to determine if Rivnut® can be removed
5. Repeat steps 1 thru 4 three times

Results

Both of these tests essentially are testing the exact same theory. Consequently, the results from both tests are the same. Figure 47 shows that the Rivnut® fails in a manner similar to if no material has been removed.

Figure 47. Rotary Tool Material Removal Results.

Figure 48 shows the results from removing material from the inside of the Rivnut®, via a lathe, before installation.

Figure 48. Material Removal from Inside Rivnut® Results.

The Rivnut® will not stretch out enough, even under modifications, to allow it to be removed from the hole. The final conclusion from this test is that to remove the Rivnut® the compressed ring of material has to be removed or separated from the Rivnut®.

APPENDIX J: MAGNET TEST

One idea to remove the shavings from the vehicle was to not let the shavings fall down to an unreachable area. This could be done by use of a magnet. A ring magnet was placed around the Rivnut® while it was being drilled out to observe if the magnet caught any, or all of the shavings that were made. Also, the distance that shavings can be drawn to the magnet was measured.

Experimental Setup

Magnet with Drill Test

The experiment was set up similar to the setup in the shavings test. Paper was put into a vise to catch any shavings that fell through the threaded end of the Rivnut®. Parallel plates were put on top of the paper to hold the sheet metal that held the Rivnut® in place while drilling occurred. This setup can be seen in Figure 52 below.

Magnet Distance Test

Shavings from various tests were placed on the table. The magnet was then slowly lowered by hand to get an approximation of the strength of the magnet.

Magnet with Woodruff Key Seat Cutter Test

This magnet test consisted of a round magnet placed over the top of the Rivnut® on the prototype fixture. The back of the Rivnut® and shavings were then placed underneath the sheet metal and the distance was measured. This can be seen in Figure 49 below.

Figure 49. Magnet on Sheet Metal.

Procedure

Magnet with Drill Test

1. Place Rivnut® into sheet metal and collapse it

2. Place ring magnet around the flange end of the Rivnut®
3. Place sheet metal into clamping device on drill press and secure
4. Center 0.90932 cm diameter drill relative to center of Rivnut®
5. Plunge drill into Rivnut® until it is cut into two pieces
6. Observe shavings on and around magnet
7. Repeat steps 1-6 varying step 2 by placing the magnet in various places

Magnet Distance Test

1. Place shavings on a table
2. Lower magnet until shavings are attracted to it
3. Record distance

Magnet with Woodruff Key Seat Cutter Test

1. Place Rivnut® into sheet metal and collapse it
2. Place ring magnet around the flange end of the Rivnut®
3. Place back of Rivnut® and shavings under sheet metal and measure distance they travel
4. Place rod magnet into hole
5. Rotate rod magnet around to find threaded portion of Rivnut®
6. Position threaded portion near the hole
7. Remove rod magnet and threaded portion
8. Place rod magnet back in hole
9. Remove cylinder magnet
10. Remove rod magnet from hole making sure to not lose any shavings from rod magnet

The rod magnet can be seen in Figure 50 below.

Figure 50. Rod Magnet and Round Magnet in Prototype Fixture.

Results

Magnet with Drill Test

There were four positions of the ring magnet that were tried in the experiment, as described below.

Magnet on Top - Middle

The results of most of the tests were successful. The first experiment was done with the ring magnet being placed around the Rivnut® as seen in Figure 51 after the test was performed.

Figure 51. Ring Magnet After Drill Use.

Observing the bottom piece of paper, there were no shavings that fell through the bottom of the Rivnut®. All the shavings either stuck to the magnet, or exited through the flange end.

Magnet on Bottom - Middle

The next experiment was done with the ring magnet around the Rivnut® on the bottom of the sheet metal. As can be seen in Figure 52 below, there were no shavings that fell through the bottom of the Rivnut® that the magnet did not attract.

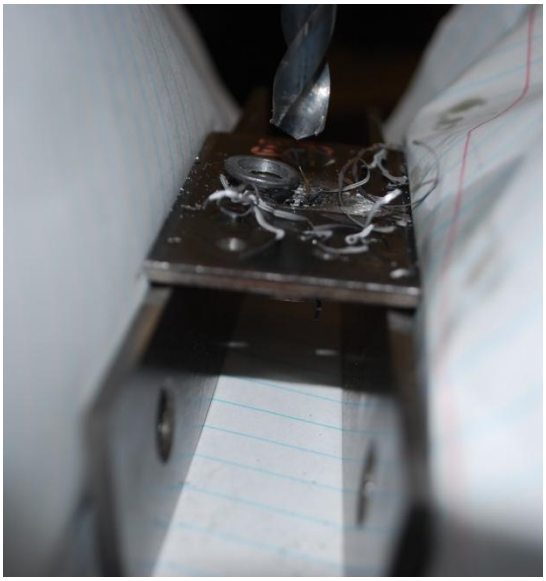


Figure 52. Magnet on Bottom Middle.

Magnet on Top – Side

The next experiment was done with the ring magnet being placed on the side of the Rivnut®. As can be seen in Figure 53, only a very small shaving fell through the bottom of the Rivnut®.

Figure 53. Magnet on Top Side.

Magnet on Bottom - Side

The last placement of the magnet that was tried was to place it on the bottom of the sheet metal to the side of the Rivnut®. As can be seen in Figure 54 below, there were also no shavings that fell through the bottom of the Rivnut® that the magnet did not attract.

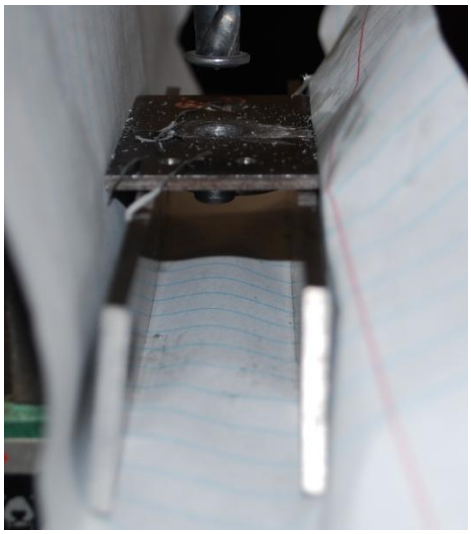


Figure 54. Magnet on Bottom Side.

These tests should be compared to what happens when a magnet is not present when drilling out the Rivnut®. Percent values can be found in Appendix H, and a picture of how many shavings fall through the Rivnut® is found in Figure 55 below.

Figure 55. Shaving Distribution without Magnet.

When a magnet is not present, some shavings fall through the bottom of the Rivnut®, which makes it difficult to retrieve them. Therefore, a magnet should be used when using a cutting operation to remove a Rivnut®.

Magnet Distance Test

The results of this test can be seen in the table below.

Table 14: Magnet Distance Test.

Shaving Type	Distance [mm]
Dust like shavings- Appendix H, Figure 11	10
Larger shavings - Appendix H, Figure 31	12

The distance the shavings traveled were about the same, but did vary a little. This test was done to get an idea of the strength of the magnet, in which the pull is rated at 5.8 N.[9] In respect to other ring magnets that are available this is a relatively weak magnet.

These results show that a magnet can be used almost anywhere near the Rivnut® in order to collect shavings to keep them from falling when a drill bit is used. Further testing must be done with other tools to determine if this is a feasible option.

Woodruff Key Seat Cutter Test

The cylinder magnet successfully held the shavings and threaded portion of the Rivnut® in place on the underside of the sheet metal after they were attracted, as can be seen in Figure 56. The distance the Rivnut® back and shavings traveled was about 2 cm. The rod magnet successfully removed the shavings from the hole, and was strong enough to pull the threaded portion of the Rivnut® through the hole. The time it takes to completely remove the threaded portion and shavings are shown in Table 15 below.

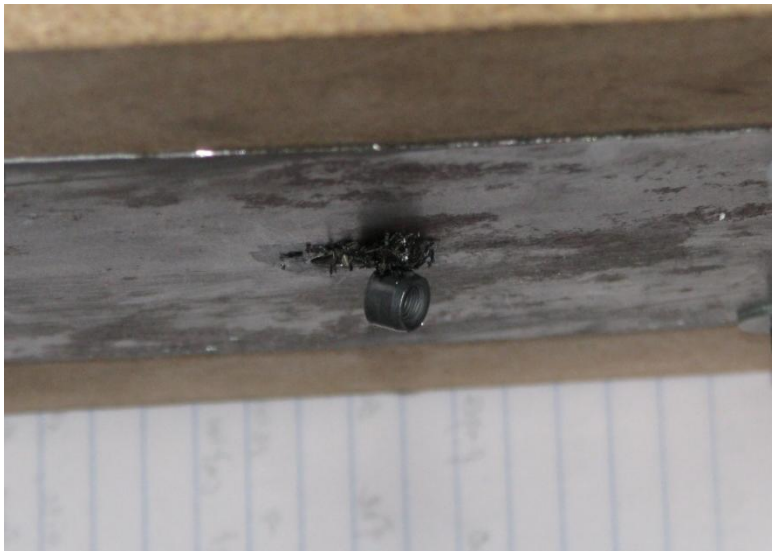


Figure 56. Threaded Portion Being Removed from Hole.

Table 15. Threaded Portion of Rivnut® Removal Time

Test Number	1	2	3	4	5	6	7	8
Time [s]	15	37	19	23	18	25	31	22

The average time of the values in Table 15 is 24 seconds.

The magnets provided enough force to gather all shavings from the Rivnut® and enable the process to be clean and not leave any shavings inside the vehicle. The rod magnet was strong, and accurate enough to enable the user to remove the threaded portion of the Rivnut® without needing a specially designed fixture to grasp the piece to pull it through the hole.

APPENDIX K: WOODRUFF KEY SEAT CUTTER TEST

It was necessary to conduct several tests to ensure that the woodruff key seat cutter design will work as desired. Once the correctly sized woodruff key seat cutter was obtained, some preliminary tests were conducted. First off, a plastic replica of a compressed Rivnut® was made and the compressed ring was cut from the body of the Rivnut®. This allowed the concept to be tested and the apparatus to be correctly set up with no danger of damaging the cutter bit. In the next test, the Rivnut® was fixed rigidly to a bolt and a large block that could easily be fixed in the apparatus. This allowed the compressed ring to be cut with no possibility of the Rivnut® rotating and damaging the Rivnut®. In the final two tests the Rivnut® was fixed in sheet metal, just as it would be in a car body. The compressed ring was then removed from the Rivnut®.

Experimental Setup

All the tests run used the same basic setup with small variations in the way that the Rivnut® is fixed. As can be seen in Figure 58, the basic setup consists of a milling machine. A rotary table was fixed to the mill table while the woodruff key seat cutter was fixed to the spindle. The center of the rotary table was centered directly below the spindle of the mill.

Preliminary Tests

The first test to run was with the plastic Rivnut®. Figure 57 shows the setup for this test. The purpose of this test was to ensure that the team knew how the setup would work once a real Rivnut® was tested.

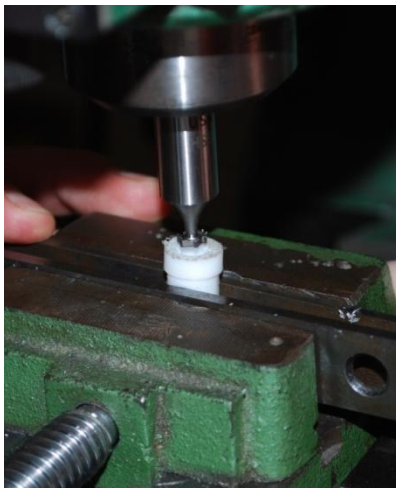


Figure 57. Experiment Setup for Plastic Rivnut®.

In the second test the Rivnut® was welded rigidly to a bolt and the bolt was welded to block of steel that was fixed to the vise on the rotary table. Figure 58 shows this setup.

Figure 58. Experiment Setup for Fixed Rivnut®.

Final Tests

These tests are the most accurate representations of how the Rivnut® will actually be removed in the final design. In the first of these tests the Rivnut® was fixed to a piece of sheet metal that was fixed in the vise on the rotary table. Figure 59 shows how this is set up.

Figure 59. Experiment Setup for Rivnut® in Sheet Metal (#1).

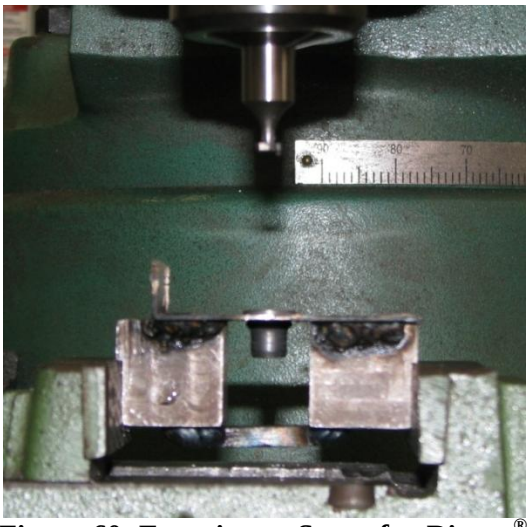


Figure 60. Experiment Setup for Rivnut® in Sheet Metal (#2).

The final test was very similar to the previous one, but in this test, the Rivnut® was set in a much more rigid setup. Figure 60 shows how this test was set up. The purpose for this test was to represent the removal process in the most accurate fashion possible.

Procedure

Again the procedure for cutting out these Rivnuts® is similar in all the tests with slight variations.

1. Once centered the woodruff key seat cutter is plunge the desired depth into the Rivnut®, with the mill spindle spinning
2. Next the table is moved on the positive Y axis direction until the shank of the cutting bit comes into contact with the inside diameter of the Rivnut®
3. Using the rotary table the Rivnut® is turned 360° in the counter-clockwise direction. This will cut out the entire compressed ring on the Rivnut®

The exact parameters for the final tests are included below in Table 16. These parameters show how to exactly run the final tests to ensure accuracy.

Table 16. Woodruff Key Seat Cutter Test Parameters.

Test	Cuts	Mill RPM	Initial Drill Ø (mm)	Final Drill Ø (mm)	Vertical Plunge (mm)	Sheet Metal Thickness (mm)
Setup (#1)		1115	6.91	9.09	4.44	1.4
Setup (#1)	1st Cut	1115	6.91	9.09	5.21	1.4
	2nd Cut	1115			3.56	
Setup (#1)	1st Cut	1115	6.91	9.09	6.35	1.4
	2nd Cut	1115			2.79*	
Setup (#2)	1st Cut	1115	6.91	9.09	5.72	1.4
	2nd Cut	1115			2.54*	
* Note: In all other vertical plunge depths the distance is measured with the bottom of the cutter lined up with the top of the Rivnut® flange. But for the starred dimensions the measurements are to be taken with the top of the cutter lined up with the top of the Rivnut® flange.						

In these final test it is necessary to drill out the inside diameter of the Rivnut® to ensure that the woodruff key seat cutter has the required clearance in the Rivnut®. Additionally two cuts have to be made with the woodruff key seat cutter because it is not thick enough to completely remove the entire compressed ring with only one cut, as seen below in Figure 61.

Figure 61. Partially Cut Compressed Ring.

This can be remedied by purchasing a woodruff key seat cutter of correct dimensions. Table 17 shows the dimensions for the cutter in these tests along with the dimensions of the cutter that is needed to completely remove the compressed ring from the Rivnut® in the future.

Table 17. Woodruff Key Seat Cutter Dimensions.

Cutter	Cutter Ø (mm)	Cutter Width (mm)	Shank Ø (mm)
These Tests	6.35	1.59	12.7
Future Tests	6.35	3.18	12.7

Results

Figure 62 shows the result of the test where the Rivnut® was fixed. This was not an accurate test because in actuality the Rivnut® will not be fixed, but the sheet metal will be fixed. This test illustrated that the woodruff key seat cutter will accomplish the task of cutting out the compressed ring.

Figure 62. Results From Fixed Rivnut® Test.

Figure 63 shows the cut Rivnut® from the first test using the setup (#1). As can be seen there is a flange on the back side of the sheet metal that will not allow the Rivnut® to be completely removed. Once this was realized it was decided that two separate cuts needed to be made.

Figure 63. 1st Cut Rivnut® From (#1) Setup.

The next was test conducted with setup (#1).

Figure 64. 2nd Cut Rivnut® From (#1) Setup.

Figure 65. Completely Removed Rivnut® (#2) Setup.

These tests proved that this concept accomplishes the goal of removing the Rivnut® and now must be designed in way that will allow it to be used on a vehicle.

APPENDIX L: FIXTURE PROTOTYPE AND TESTING

The fixture for the prototype can be seen in Figure 66. The prototype fixture consisted of a single piece of particle board which was milled down using a CNC machine to proper specifications as well as a piece a sheet metal bolted to the board.

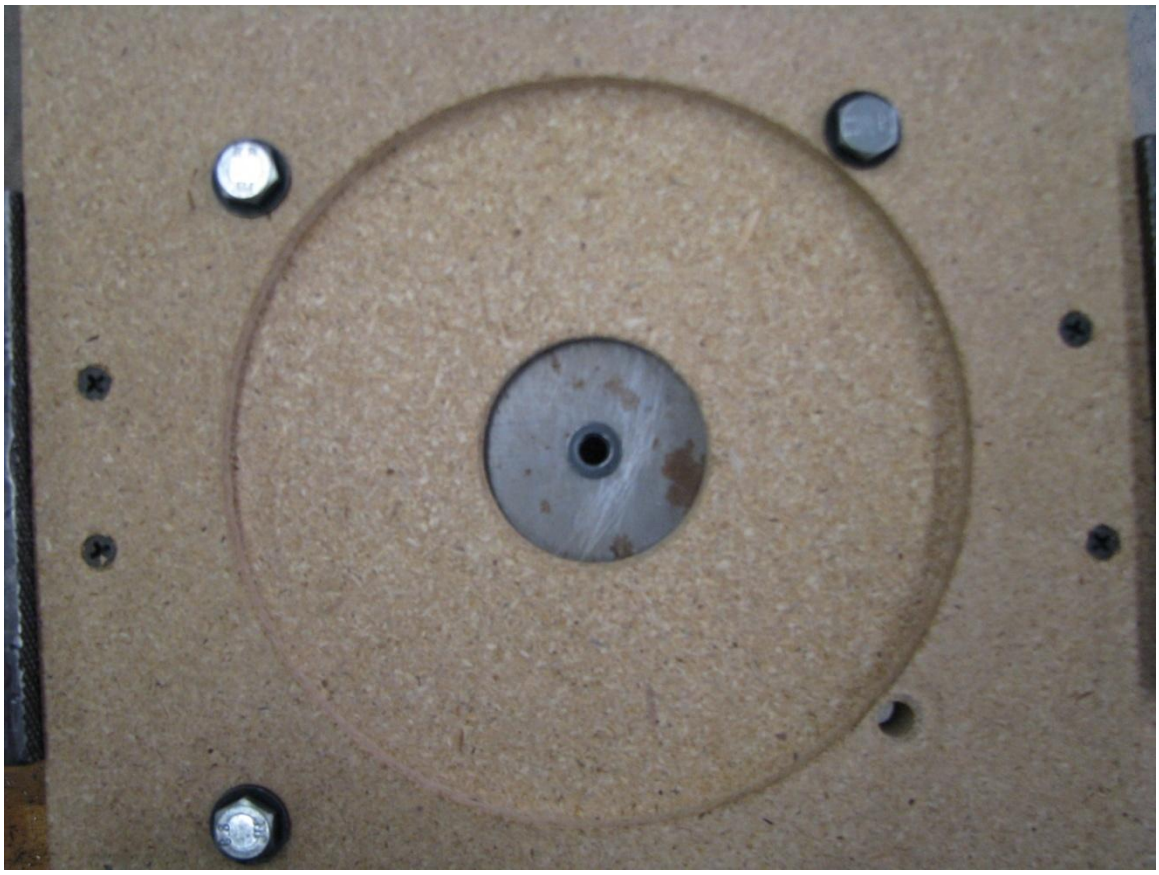


Figure 66. Fixture Prototype.

Experimental Setup

The fixture prototype was assembled from particle board, a piece of sheet metal, and two sections of 2x4 for stability. The particle board was 1.59 cm thick, 25.4 cm wide and 30.5 cm long. A router was placed on top of the fixture as seen in Figure 67. Along with using the router, a dimmer switch had to be used to get the RPMs of the router down to a lower level so that the woodruff key seat cutter would not wear quickly and become unusable. A wattmeter was used to determine the power needed to run the router at the desired speed. A stroboscope was used to determine the speed of the woodruff key seat cutter and a marker was used to determine if the surface was being scarred or scratched in any way.

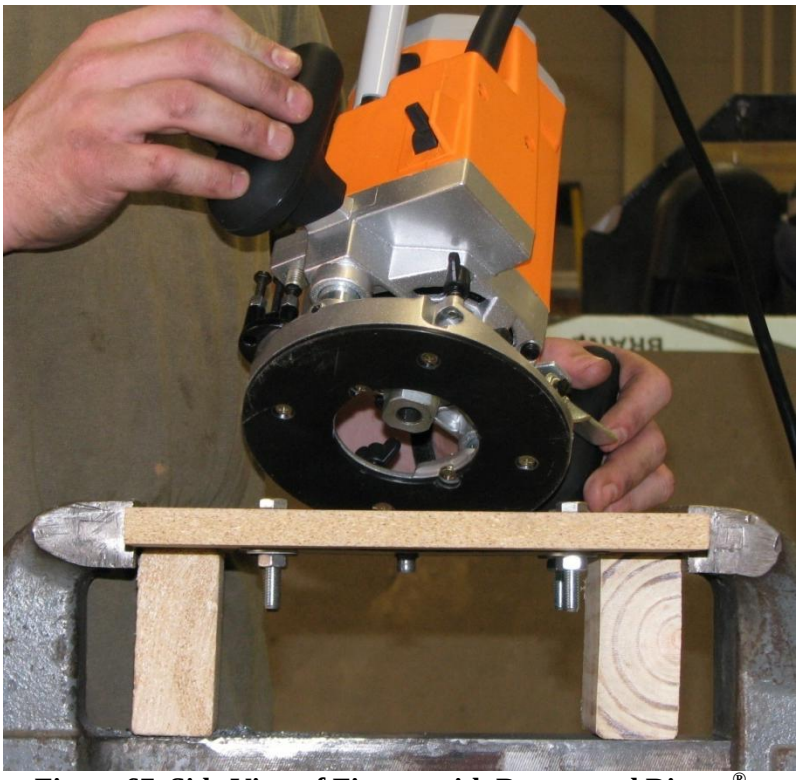


Figure 67. Side View of Fixture with Router and Rivnut®.

Procedure

Procedure for Making Fixture

1. Use a CNC Machine to get 0.762 cm hole of exact radius of 8.3058 cm in board
2. Use a hole saw of 2.54 cm radius to cut hole for sheet metal and Rivnut® to be accessed through
3. Drill hole in sheet metal for Rivnut®
4. Attach sheet metal to particle board using four bolts
5. Attach two stabilizing pieces to particle board using self-tapping wood screws

Procedure for Removing a Rivnut®

11. Drill out Rivnut® threads with drill
12. Plug router into dimmer switch and dimmer switch into wall
13. Place router with woodruff key seat cutter installed into hole cut in particle board
14. Center the woodruff key seat cutter over the Rivnut®
15. Turn on router and set to appropriate speed using dimmer switch
16. Plunge router to specified depth
17. Move router until base hits edge of cutout part in particle board
18. Move around the router in cutout portion of board until threaded portion of Rivnut® is separated
19. Use drill to remove head of Rivnut®

Procedure for Scratch Test

1. Color specified area with a permanent marker

2. Run Rivnut® Removal Test
3. Observe area that was colored after completion of the test for any scratches made to the surface.

Results

Rivnut Removal

Using the prototype fixture and router with the woodruff key seat cutter, the Rivnut® was successfully removed from the sheet metal. The Rivnut® head and removed threaded portion can be seen in Figure 68.

Figure 68. Rivnut® Head and Threaded Portion.

This fixture and set up was able to prove that the idea for using a woodruff key seat cutter to remove a Rivnut® works. As one can see from Figure 68, the entire compressed ring was not removed by the woodruff key seat cutter.

With this problem in mind, further testing was done and six out of seven Rivnuts® were removed, but still had this flange. This meant that the bottom of the Rivnut® could not be pulled back through the hole that the Rivnut® was installed. If the woodruff key seat cutter had a thicker face width(1.6 mm larger), it is hypothesized that this flange would be completely removed. For reporting purposes, it was assumed that since the flange problem could be fixed each removal was counted as a success (as though we had used the larger cutter), even though the bottom of the Rivnut® still had a flange on it.

During these tests, the dimmer switch was replaced with a Veriac in order to more accurately control the power going to the router. A digital wattmeter, seen in Figure 69, was used to determine that the router was using 108 Watts during the cutting operation.

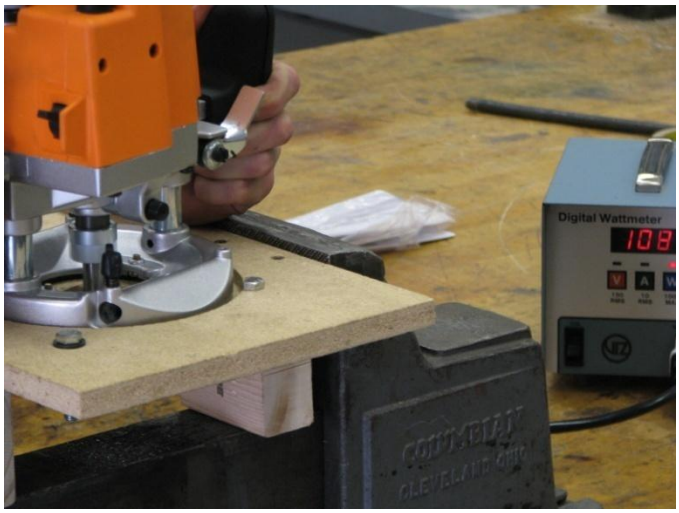


Figure 69. Digital Wattmeter Measuring Power Usage While Cutting.

A stroboscope was also used during the testing to determine at what rate the woodruff key seat cutter should rotate. This was determined to be 1550 RPM. The woodruff key seat cutter manufacturer recommends that the tool be run at 1681 RPM. Each of the seven tests that were timed and the times for each can be found in Table 18.

Table 18. Time Recorded for Removal Test.

Run	1	2	3	4	5	6	7
Time (s)	85	90	365	93	87	84	90

The average time for Rivnut® removal was calculated to be approximately 88 seconds. Test 3 was the unsuccessful removal, and can be seen as taking over 6 minutes to remove. These times of the successful removals help show that the process described in this paper works as designed.

Scratch test

The colored portion of the sheet metal can be seen in Figure 70.

Figure 70. Colored Sheet Metal.

The coloring test on the sheet metal revealed that as long as the woodruff key seat cutter does not come in contact with the sheet metal, no scratches are made to the base material.

APPENDIX M: FAILED DESIGN CONCEPTS

Replacement Concept

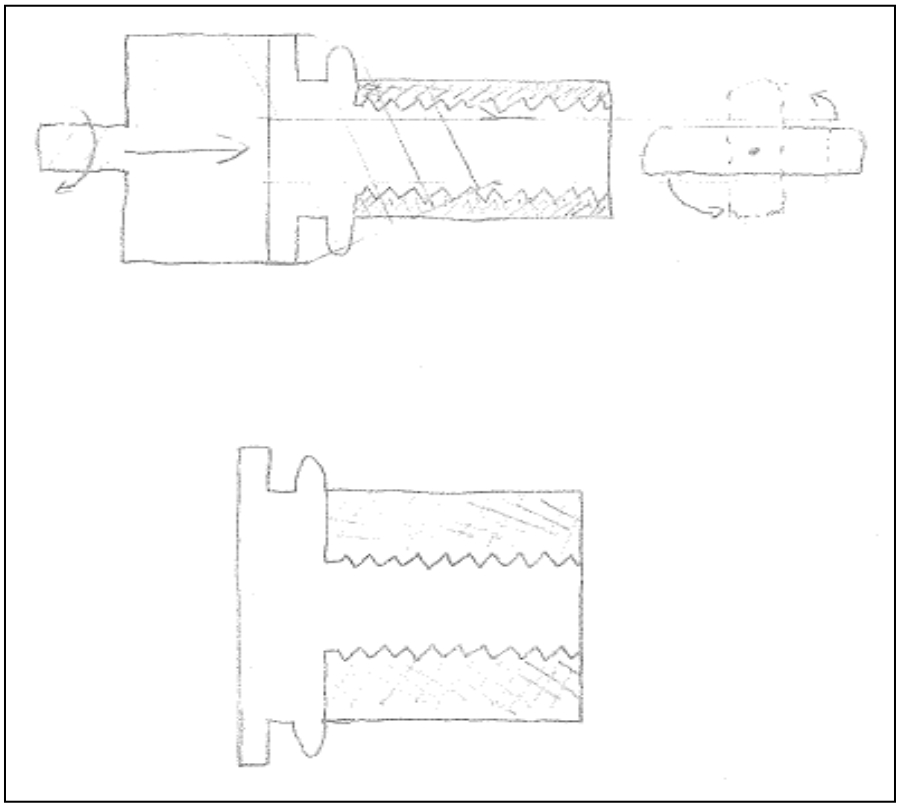


Figure 71. Replacement Concept Sketch.

This concept drills out a hole the width of the flange. This would remove the entire Rivnut®, but leave a larger hole, thus a larger Rivnut® must be put in its place. This concept was scrapped because we could not alter the base material.

Instructions

1. Insert center drill bit in damaged Rivnut®
2. Drill out Rivnut® until hole in base material is equal to diameter of the compressed ring
3. Pull out damaged Rivnut®
4. Install new Rivnut®

Note: The outside diameter of the installed Rivnut® must be equivalent to the hole size

Pros

1. Simple design
2. Fast and easy removal process

Cons

1. Can only be implemented one time for each hole
2. Drill shavings left behind
3. Modifies base material

4. If not precise, will destroy base material

Modification of Rivnut® Concept

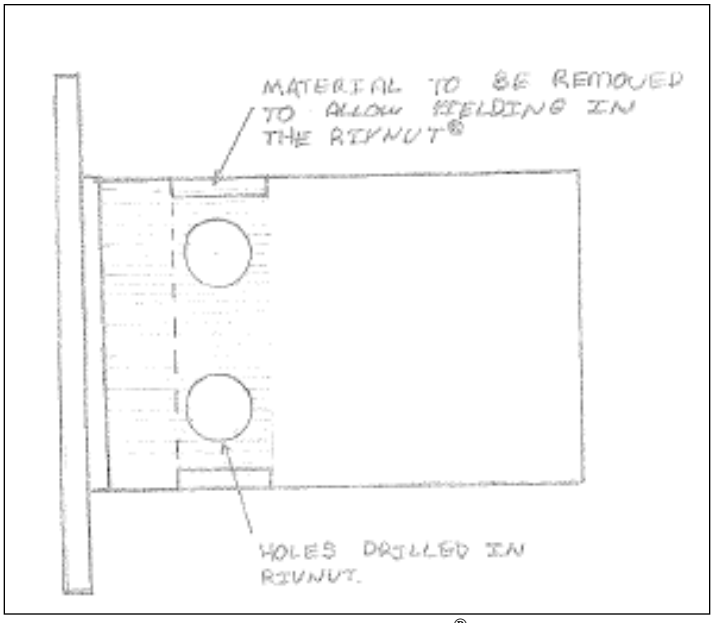


Figure 72. Modification of Rivnut® Concept Sketch.

This concept came from testing. The idea is to remove some material and drill holes in the Rivnut® to increase the possibility the Rivnut® will stretch all the way out. This concept was scrapped because the team discovered that changing the Rivnut® was not acceptable.

Instructions

1. Reduce wall thickness of Rivnut® at critical yielding area
2. Drill holes in Rivnut® in critical yielding area
3. Install Rivnut®
4. When damaged, apply axial load to elongate Rivnut® and remove

Pros

1. Leaves no material behind
2. Does not alter base material in any way
3. Fast removal and easy removal process

Cons

1. Lessens carrying capacity of Rivnut®
2. May be hard to manufacture
3. May make the Rivnut® more costly

Reciprocating Saw Concept

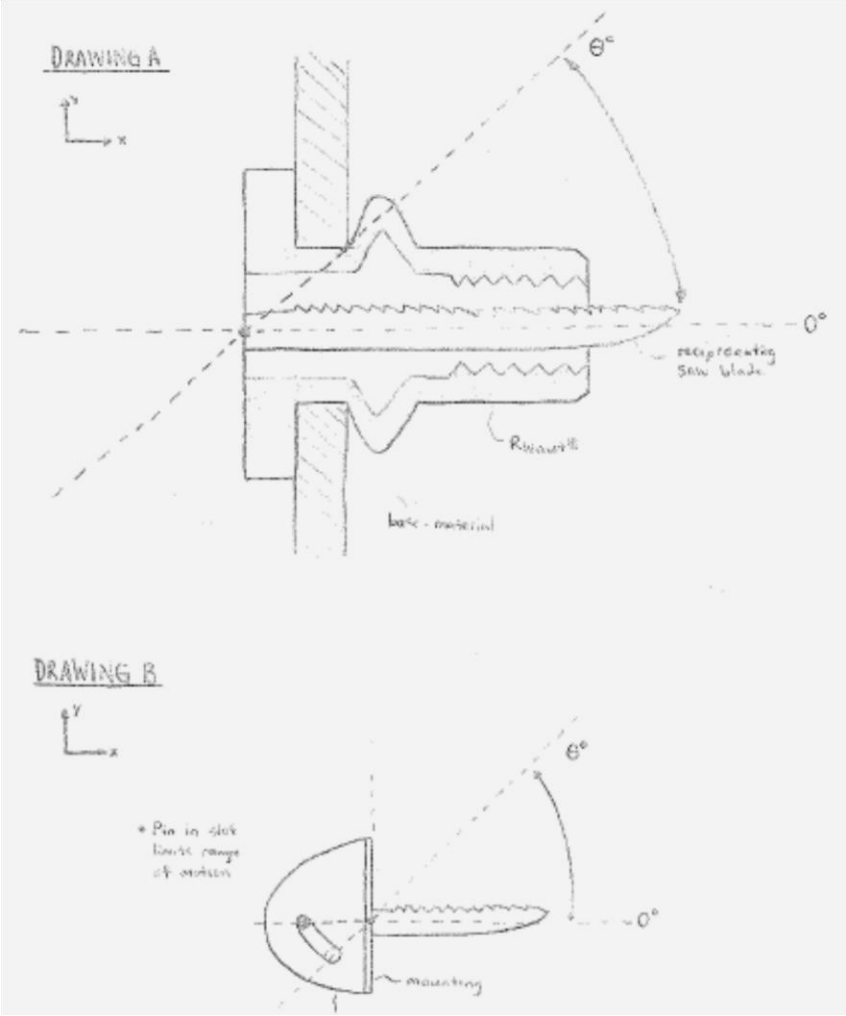


Figure 73. Reciprocating Saw Concept Sketch.

A test was performed using a hack saw to make four separate cuts along the length of the back of the Rivnut® to imitate what would occur with the Reciprocating Saw Concept. Upon inspection, it was clear that this concept would not be feasible because not enough material was able to be removed. When the Rivnut® was pulled on axially, the compressed ring still held tightly despite having 4 cuts in the length.

Instructions

1. Insert saw into Rivnut®
2. Engage saw until a slit is cut through the back side of the Rivnut®
3. Cut another slit 90º from previous cut
4. Repeat step three until four cuts are made
5. Remove saw blade
6. With clamping device, grasp Rivnut® head and pull out of hole

Pros

1. Only leaves small particles of material behind

Cons

1. Complicated multi-step process
2. Time consuming process

Hollow Mill Concept

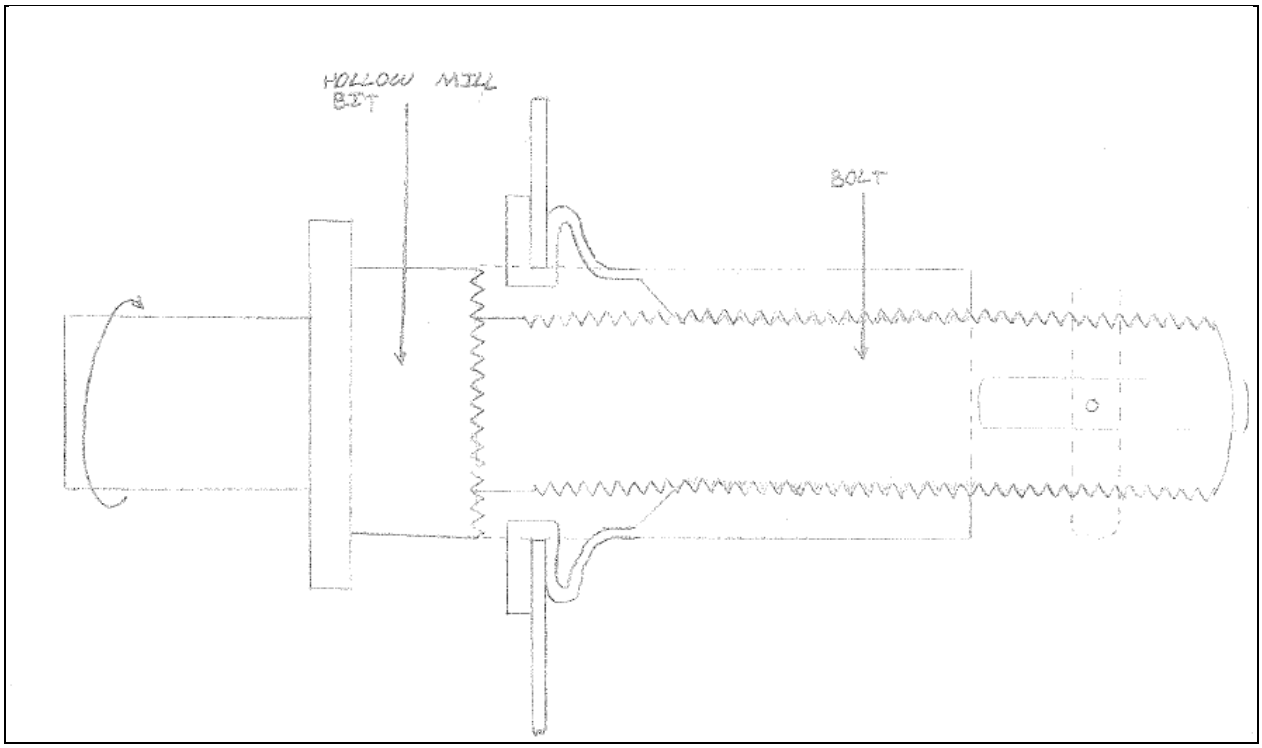


Figure 74. Hollow Mill Concept Sketch

This concept utilizes a hollow mill bit to cut out the threaded part of the Rivnut®. The bolt remains stationary while the mill bit rotates independent of the bolt. If the Rivnut® starts to rotate on the bolt, it will then be rotated towards the cutting mill bit. This will remove the compressed ring of material from the Rivnut® and allow the threaded side of the Rivnut® to be removed from the hole. The last step is to remove the compressed ring of material from the hole. This concept was reviewed and was determined that it was unfeasible to obtain a solution that would meet the constraints using this concept.

Instructions

1. Screw bolt into Rivnut®
2. With bolt stationary, engage hole saw
3. With hole saw, drill until hole saw is fully in place
4. Remove entire apparatus from hole

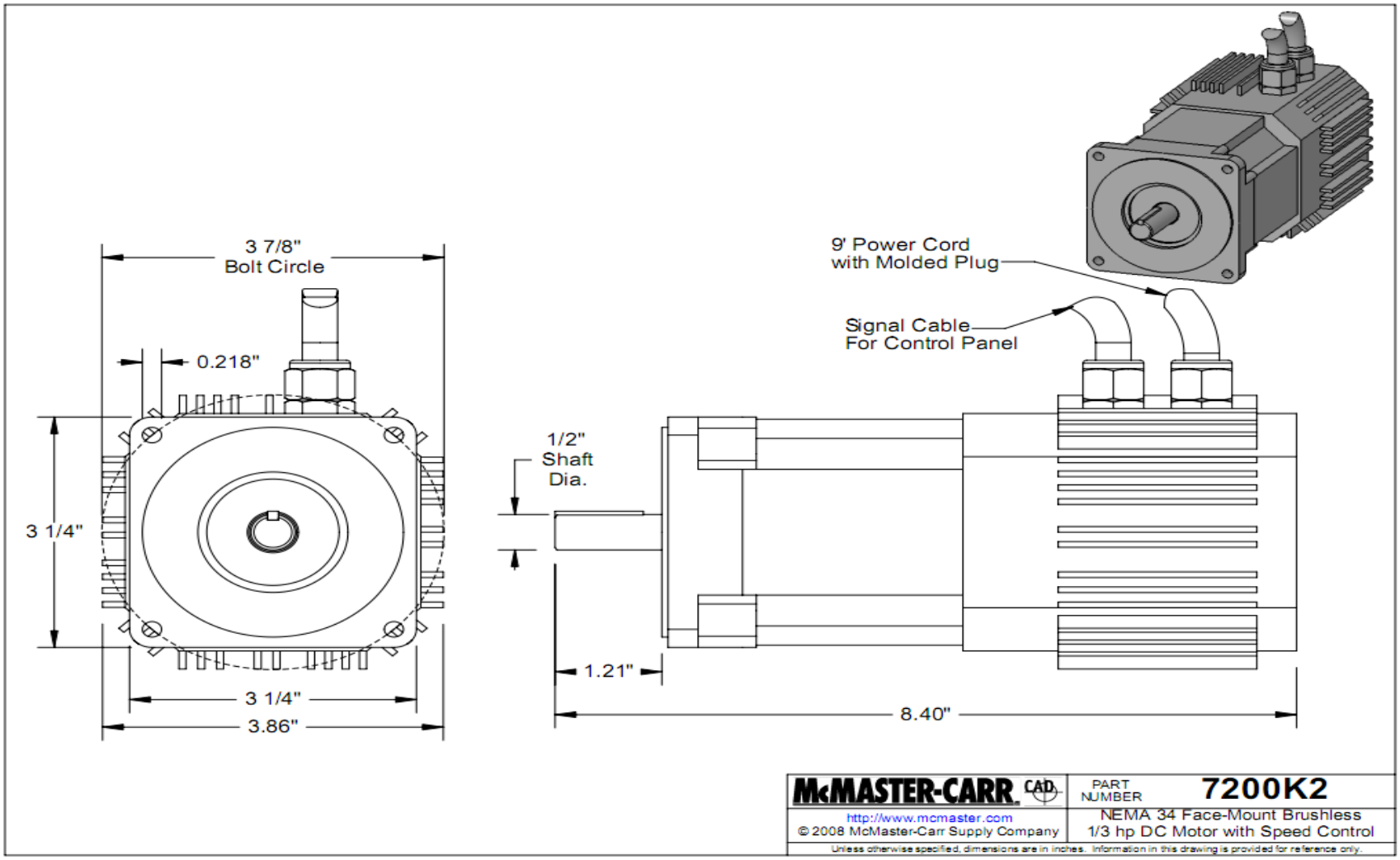
Pros

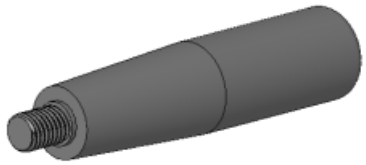
1. Does not cause damage to base material
2. User friendly operation

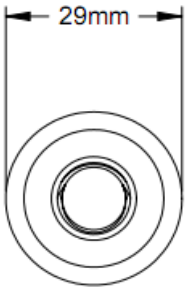
Cons

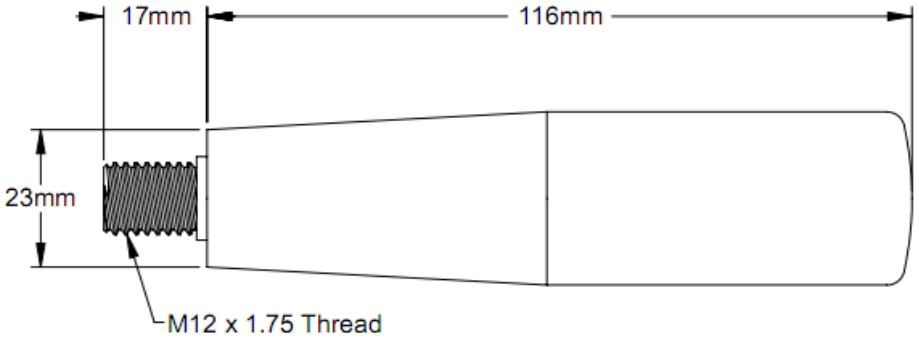
1. Leaves behind compressed ring and shavings
2. May not be usable if threads are completely stripped

APPENDIX M: DETAIL DRAWINGS









McMASTER-CARR® CAD
http://www.mcmaster.com
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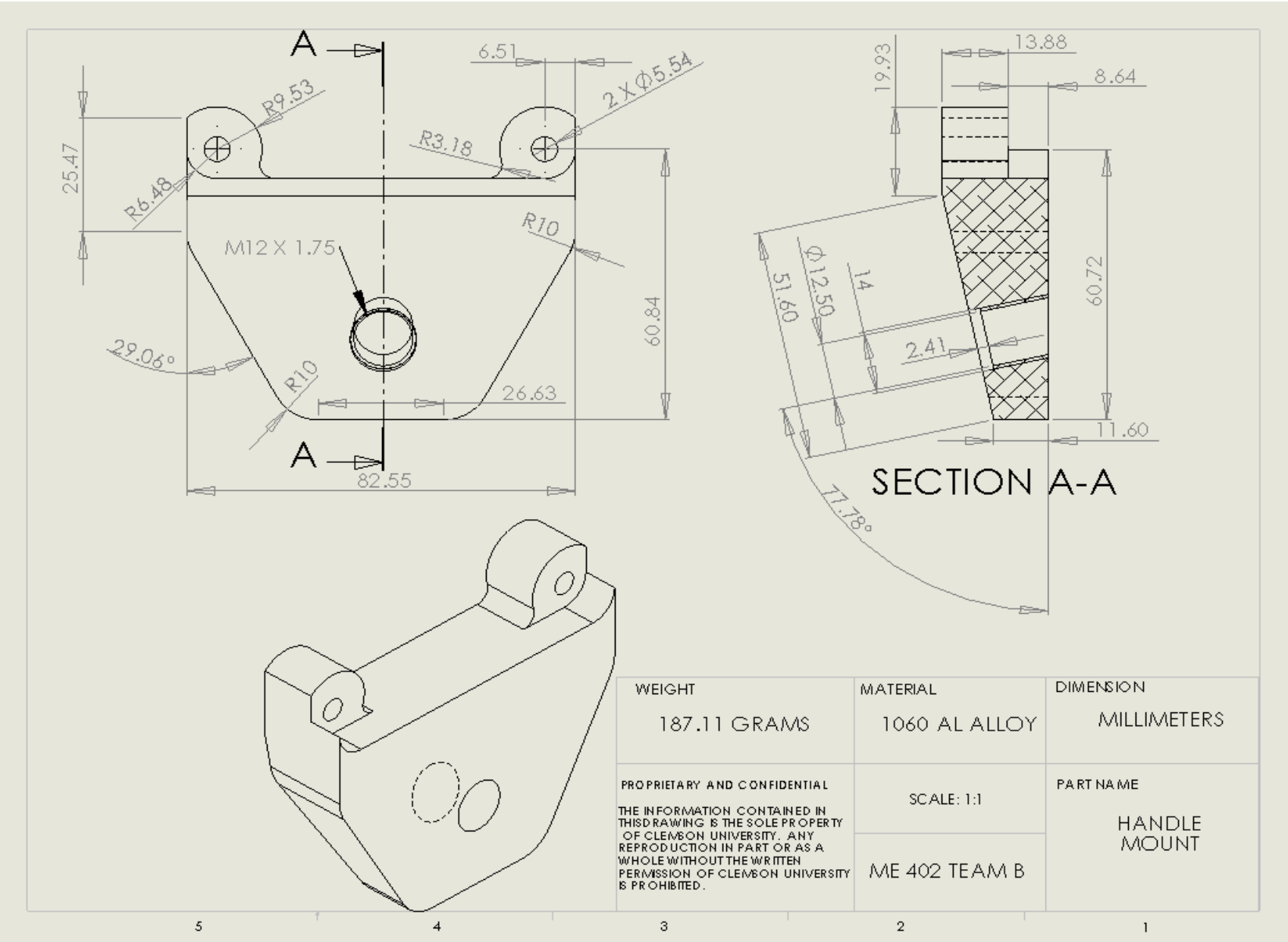
PART NUMBER 6308K53

Phenolic Tampered Handle with Threaded Stud


A
A
6.51
2 X Ø5.54
R9.53
R3.18
25.47
R6.48
R10
M12 X 1.75
60.84
29.06°
R10
26.63
82.55
19.93
13.88
8.64
Ø12.50
14
51.60
2.41
60.72
11.60
SECTION A-A
11.78°
WEIGHT
187.11 GRAMS
MATERIAL
1060 AL ALLOY
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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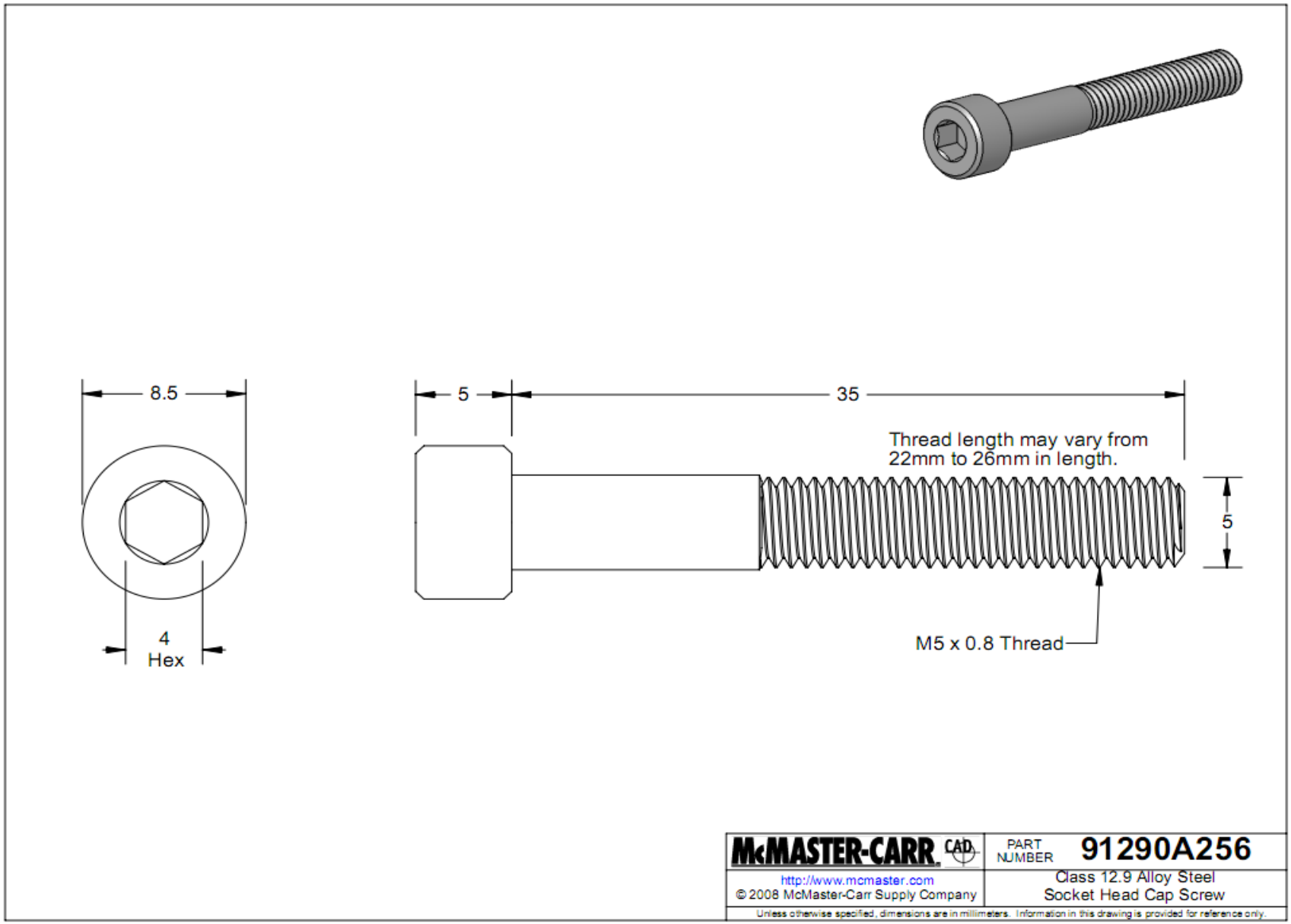
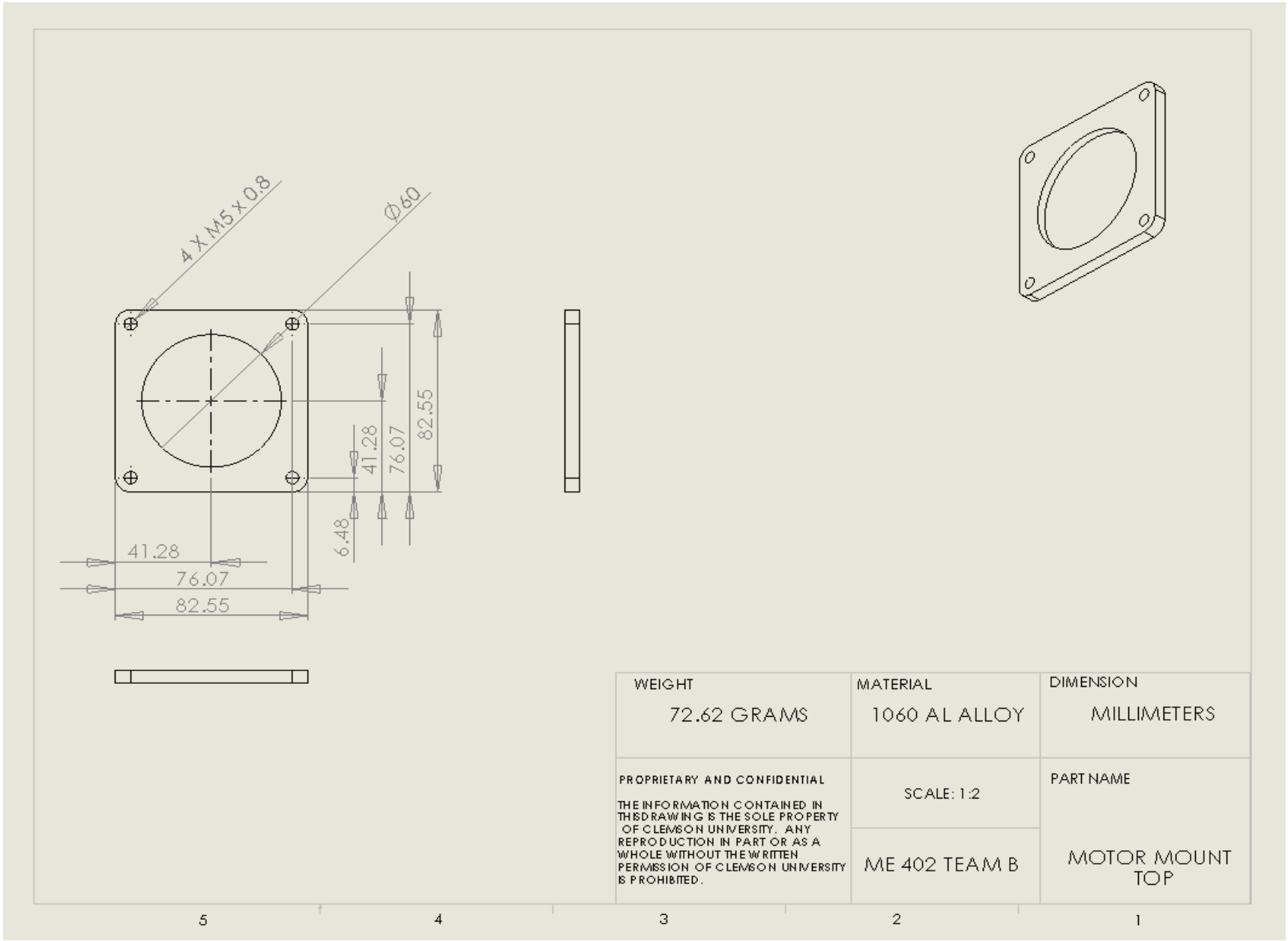
SCALE: 1:1
ME 402 TEAM B
PART NAME
HANDLE MOUNT
5
4
3
2
1


8.5
4
Hex
5
35
Thread length may vary from
22mm to 26mm in length.
5
M5 x 0.8 Thread
McMASTER-CARR CAD
PART NUMBER 91290A256
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
Class 12.9 Alloy Steel
Socket Head Cap Screw
Unless otherwise specified, dimensions are in millimeters. Information in this drawing is provided for reference only.


4 X M5 x 0.8
Ø60
82.55
76.07
41.28
6.48
41.28
76.07
82.55
WEIGHT
72.62 GRAMS
MATERIAL
1060 AL ALLOY
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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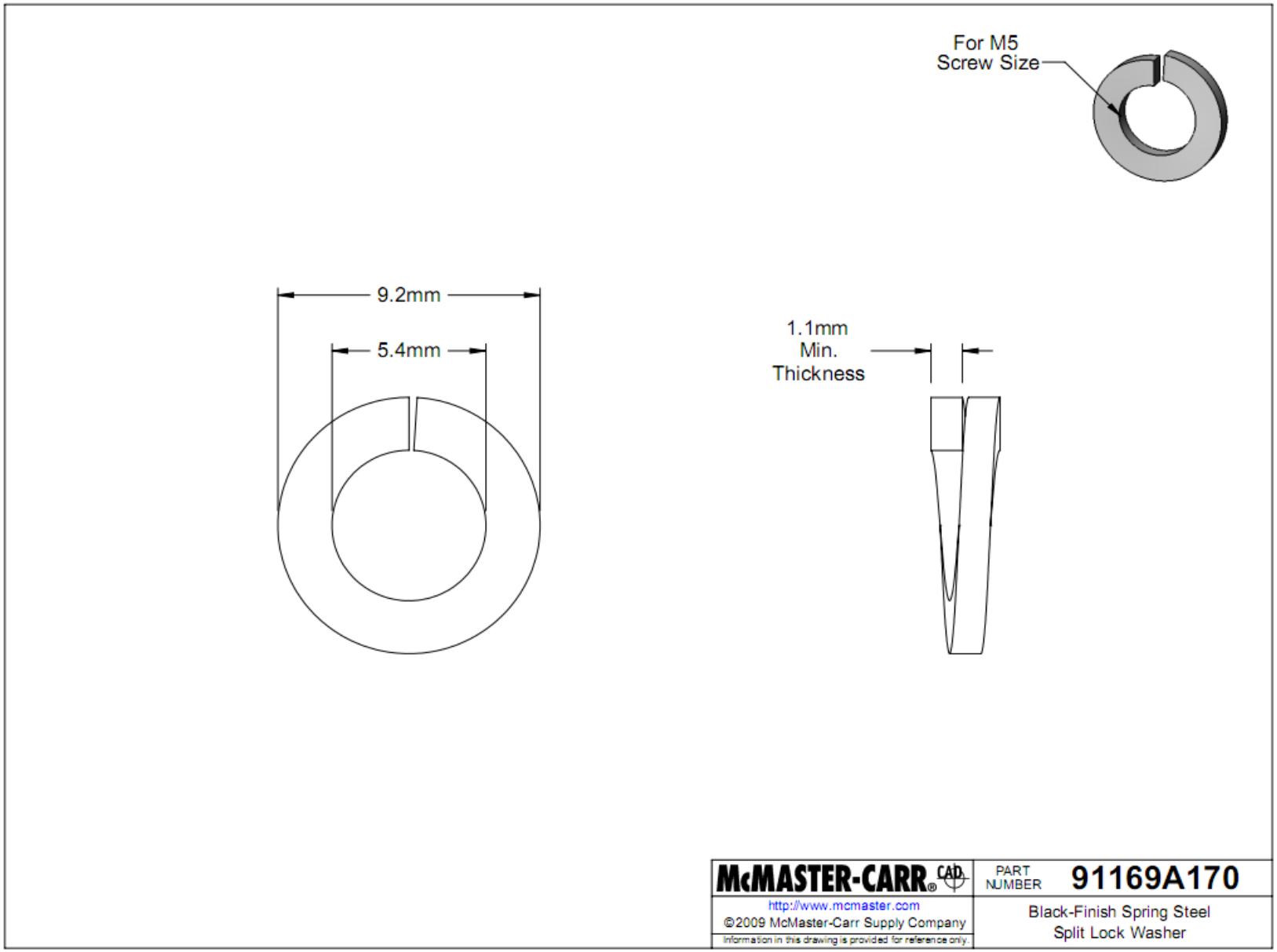
SCALE: 1:2
ME 402 TEAM B
PART NAME
MOTOR MOUNT TOP
5
4
3
2
1


For M5
Screw Size
9.2mm
5.4mm
1.1mm
Min.
Thickness
McMASTER-CARR
CAD
http://www.mcmaster.com
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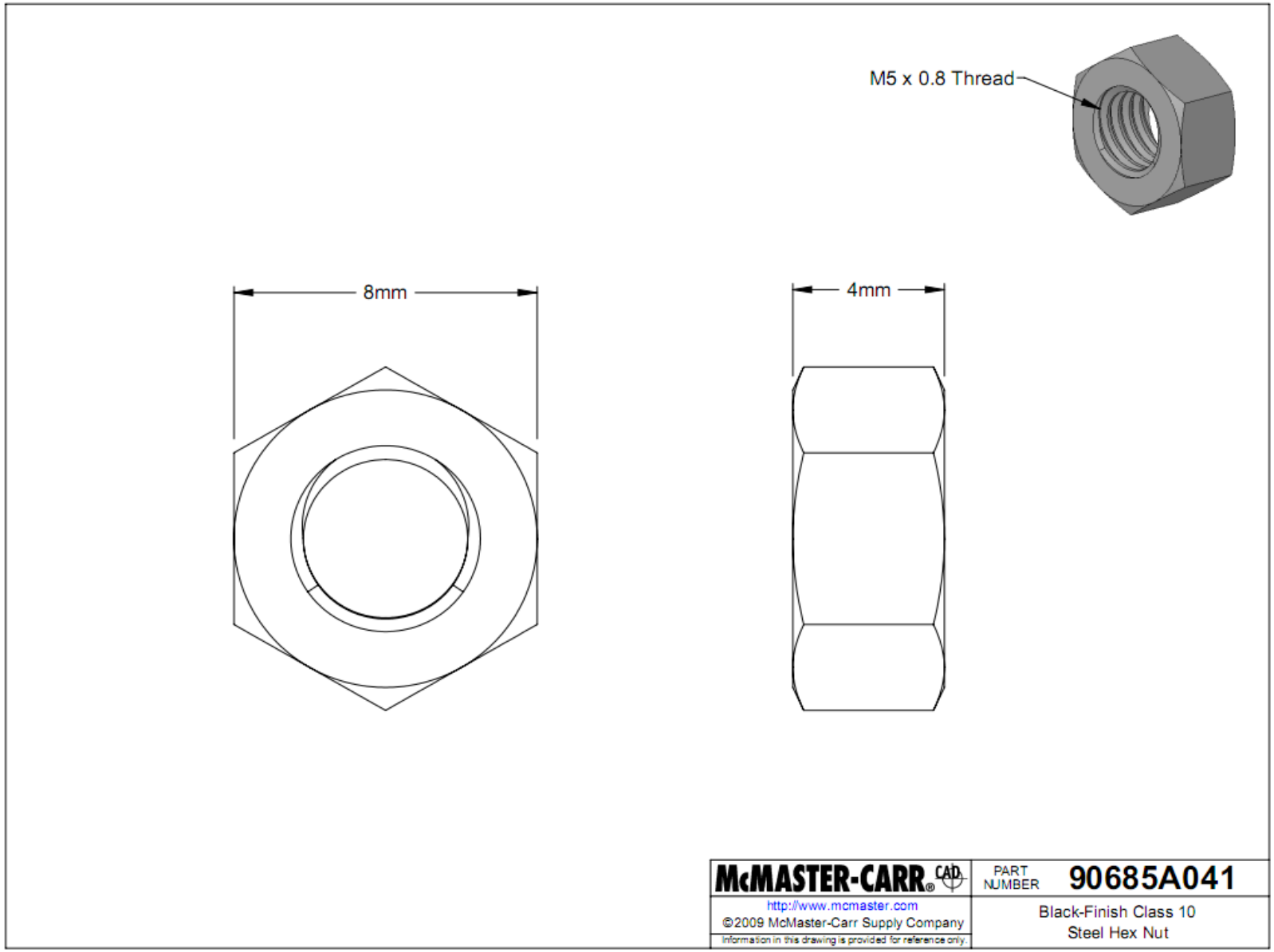
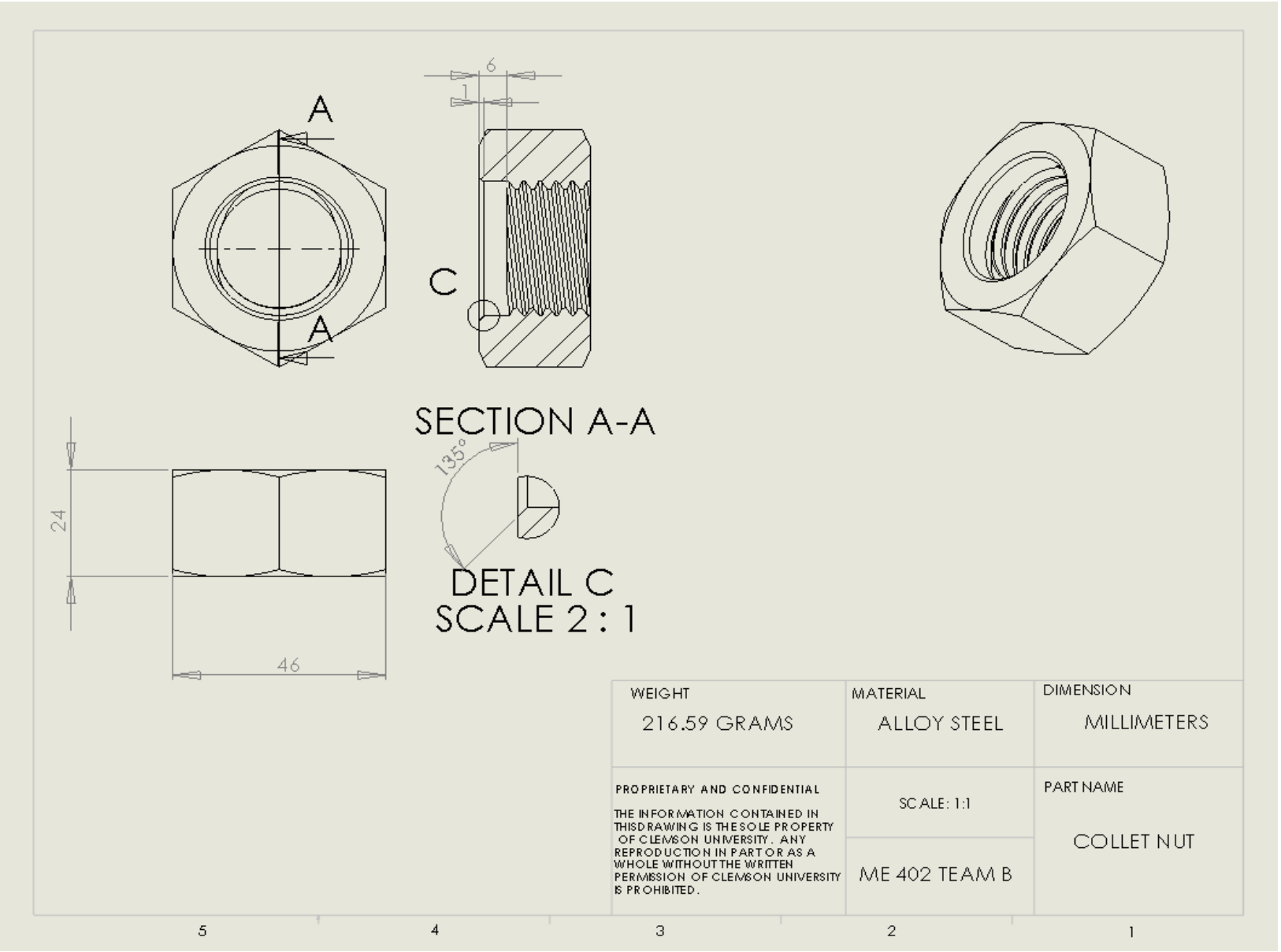
Information in this drawing is provided for reference only.
PART NUMBER
91169A170
Black-Finish Spring Steel
Split Lock Washer


M5 x 0.8 Thread
8mm
4mm
McMASTER-CARR
http://www.mcmaster.com
©2009 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER 90685A041
Black-Finish Class 10
Steel Hex Nut


A
A
6
1
C
SECTION A-A
135°
DETAIL C
SCALE 2 : 1
24
46
WEIGHT
216.59 GRAMS
MATERIAL
ALLOY STEEL
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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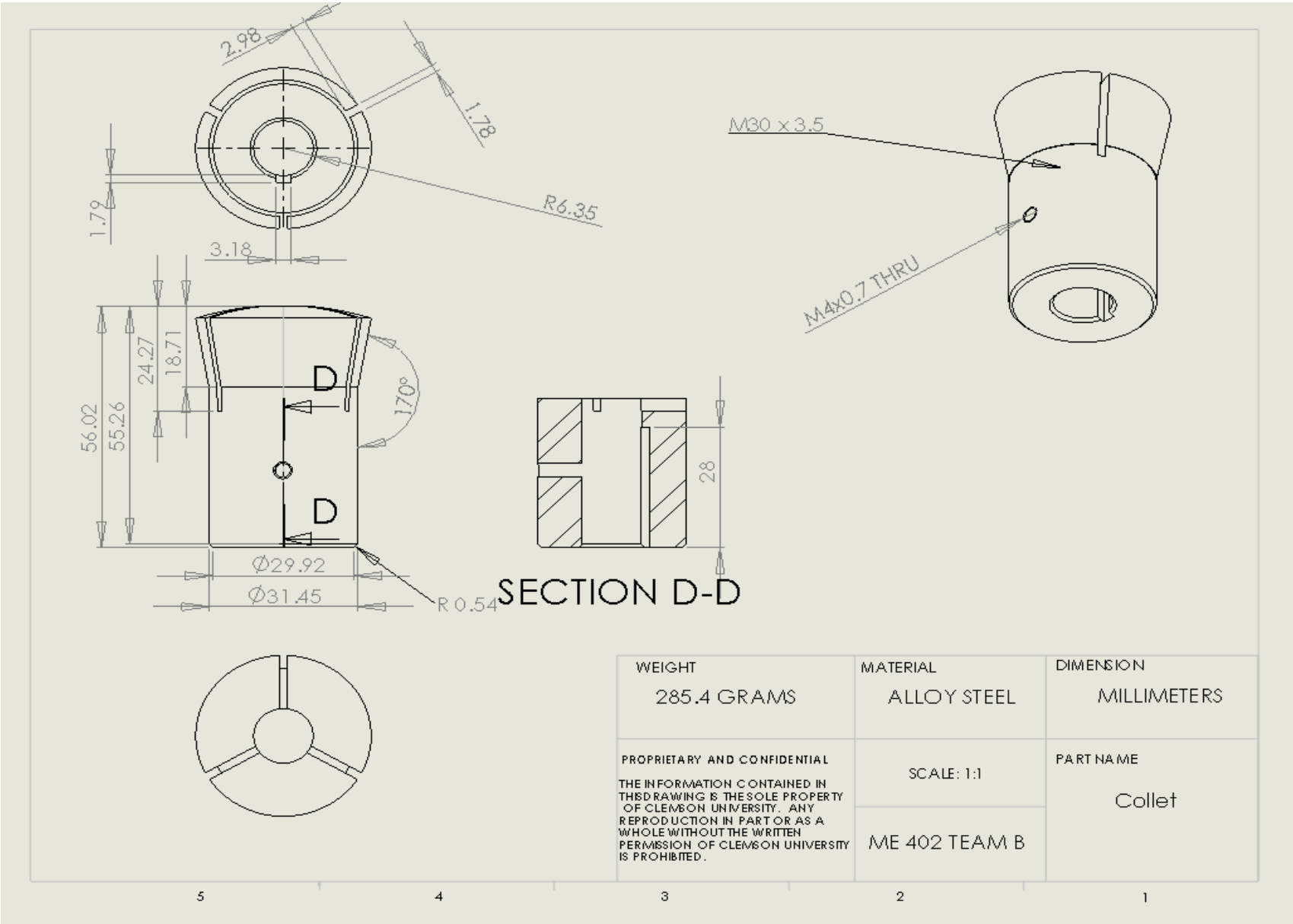
SCALE: 1:1
ME 402 TEAM B
PART NAME
COLLET NUT
5
4
3
2
1


2.98
1.78
R6.35
1.79
3.18
M30 x 3.5
M4x0.7 THRU
56.02
55.26
24.27
18.71
D
D
170°
28
Ø29.92
Ø31.45
R 0.54
SECTION D-D
WEIGHT
285.4 GRAMS
MATERIAL
ALLOY STEEL
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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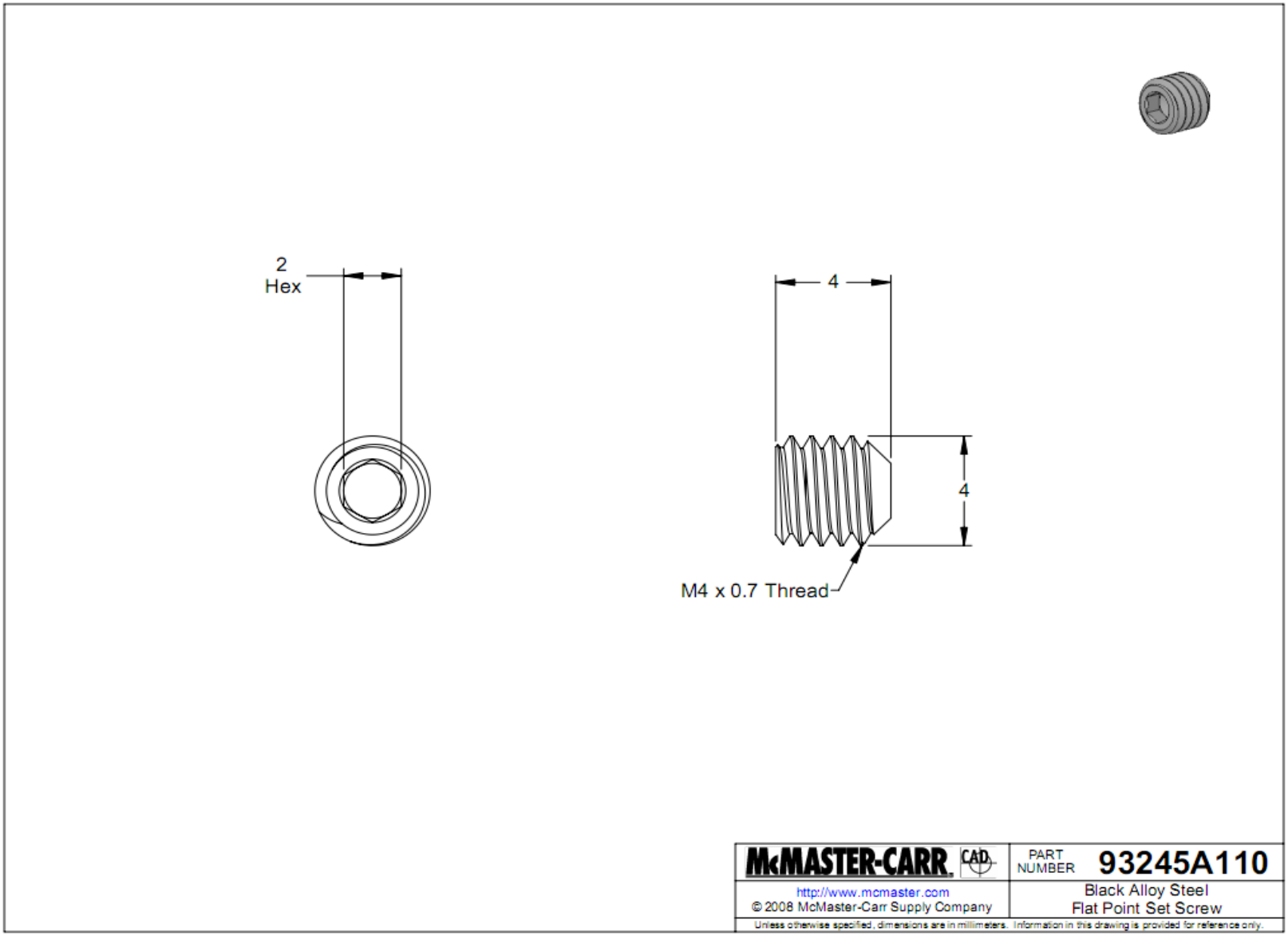
SCALE: 1:1
PART NAME
Collet
ME 402 TEAM B
5
4
3
2
1


2
Hex
4
4
M4 x 0.7 Thread
McMASTER-CARR
CAD
PART NUMBER 93245A110
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
Black Alloy Steel
Flat Point Set Screw
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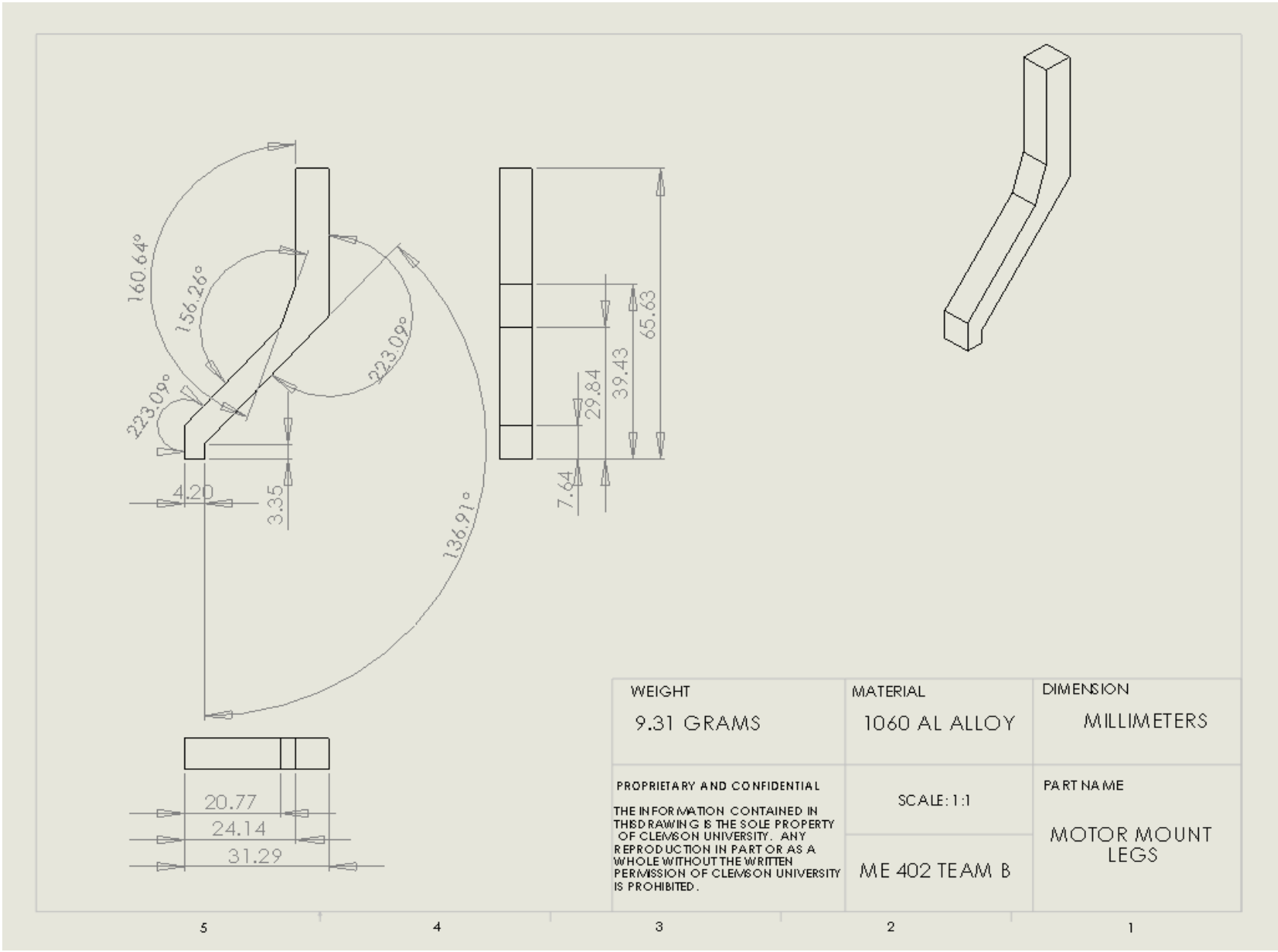
160.64°
156.26°
223.09°
223.09°
136.91°
4.20
3.35
20.77
24.14
31.29
7.64
29.84
39.43
65.63
WEIGHT
9.31 GRAMS
MATERIAL
1060 AL ALLOY
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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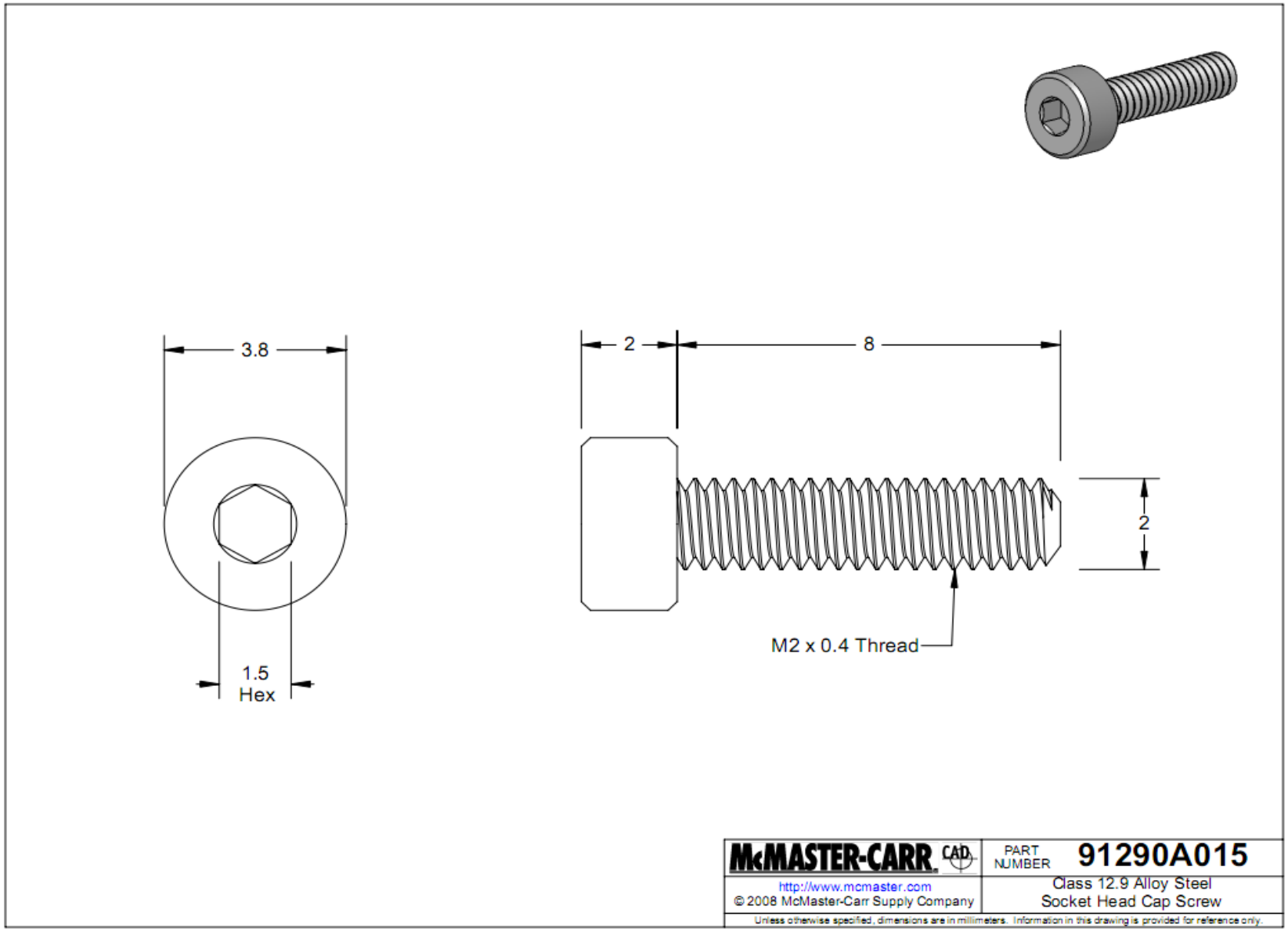
SCALE: 1:1
ME 402 TEAM B
PART NAME
MOTOR MOUNT LEGS
5
4
3
2
1


3.8
1.5
Hex
2
8
2
M2 x 0.4 Thread
McMASTER-CARR
CAD
PART NUMBER 91290A015
http://www.mcmaster.com
© 2008 McMaster-Carr Supply Company
Class 12.9 Alloy Steel
Socket Head Cap Screw
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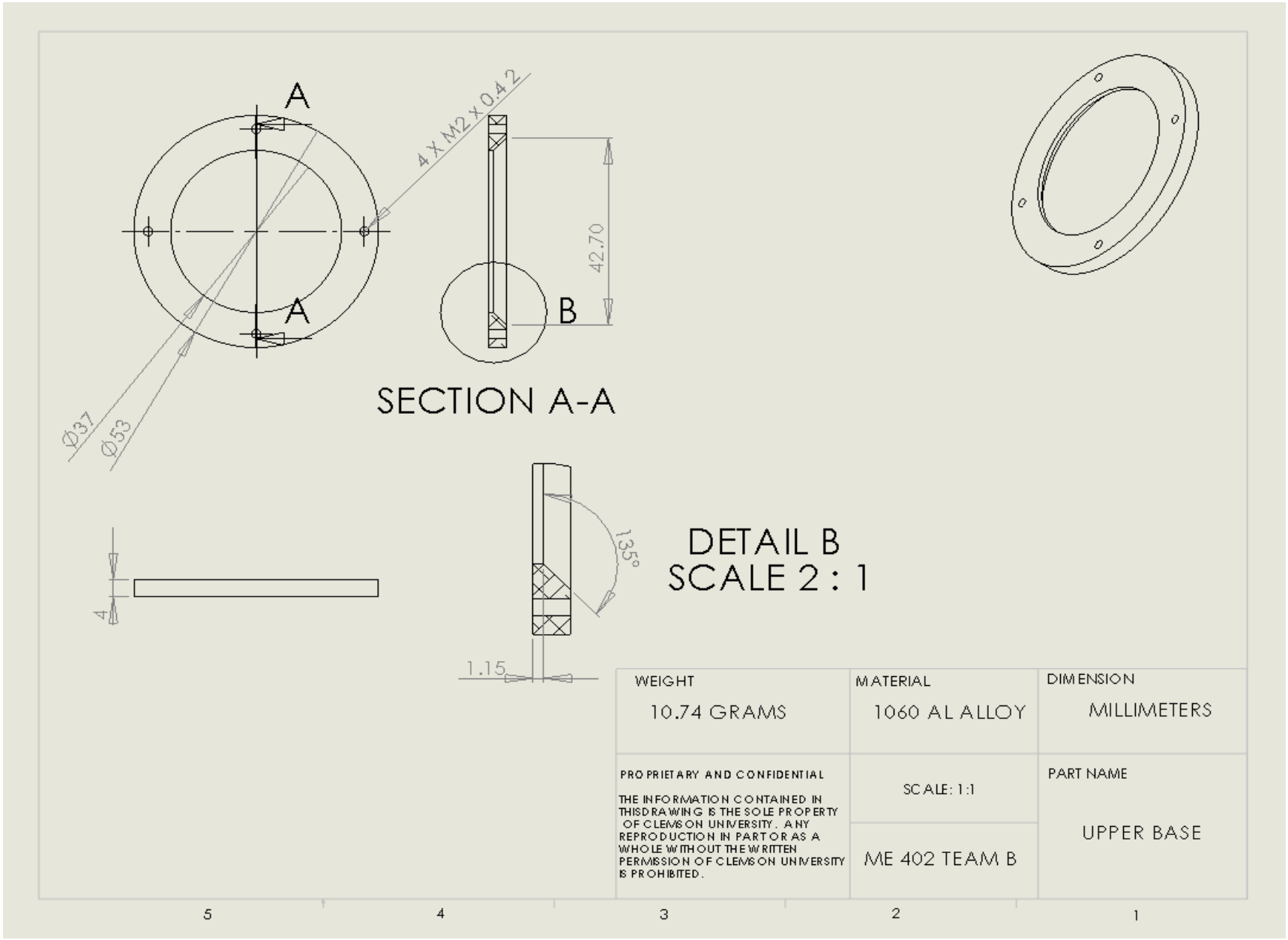
A
A
4 X M2 x 0.4 2
42.70
B
SECTION A-A
Ø37
Ø53
135°
4
1.15
DETAIL B
SCALE 2 : 1
WEIGHT
10.74 GRAMS
MATERIAL
1060 AL ALLOY
DIMENSION
MILLIMETERS
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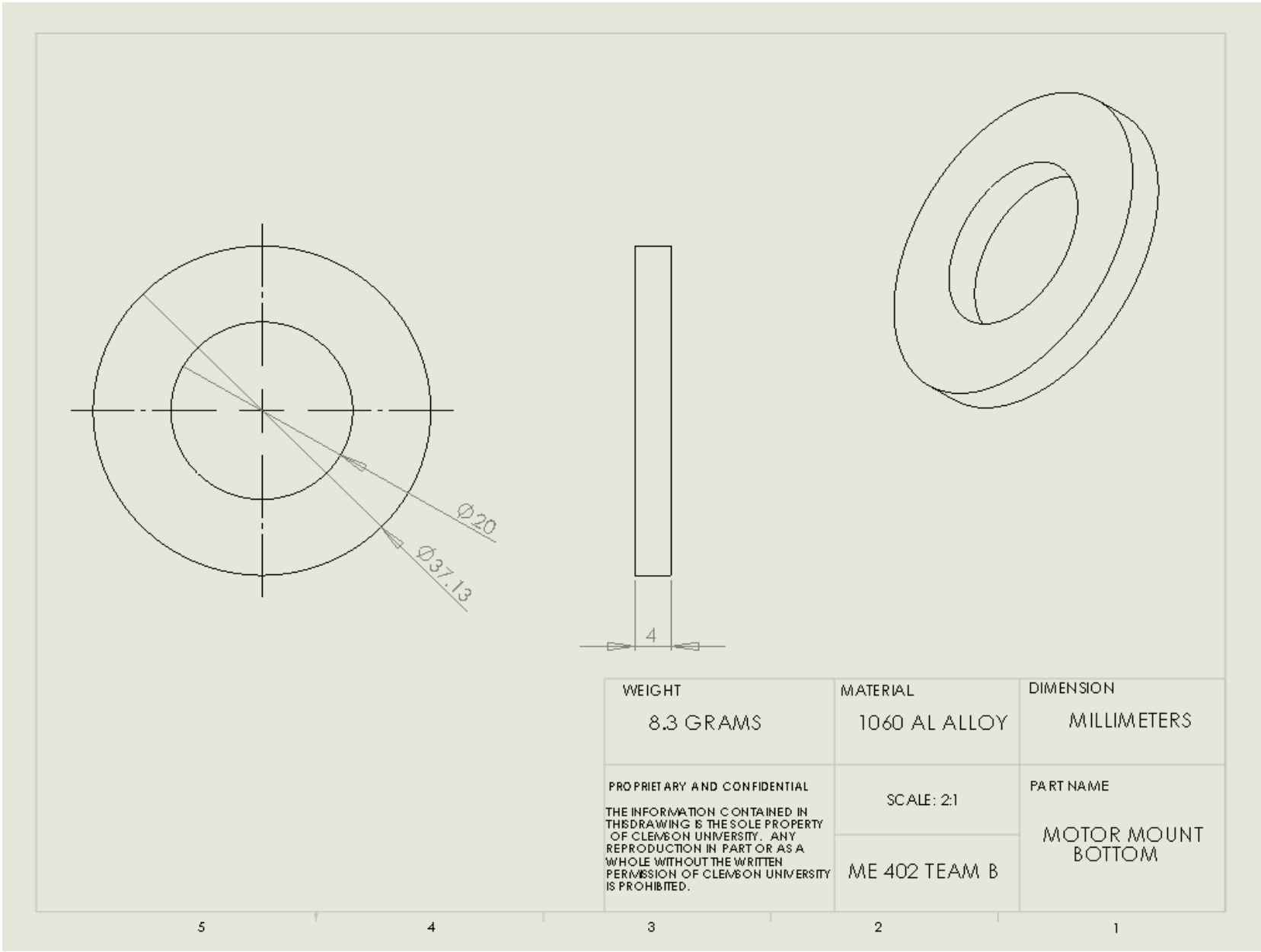
SCALE: 1:1
ME 402 TEAM B
PART NAME
UPPER BASE
5
4
3
2
1


Ø20
Ø37.13
4
WEIGHT
8.3 GRAMS
MATERIAL
1060 AL ALLOY
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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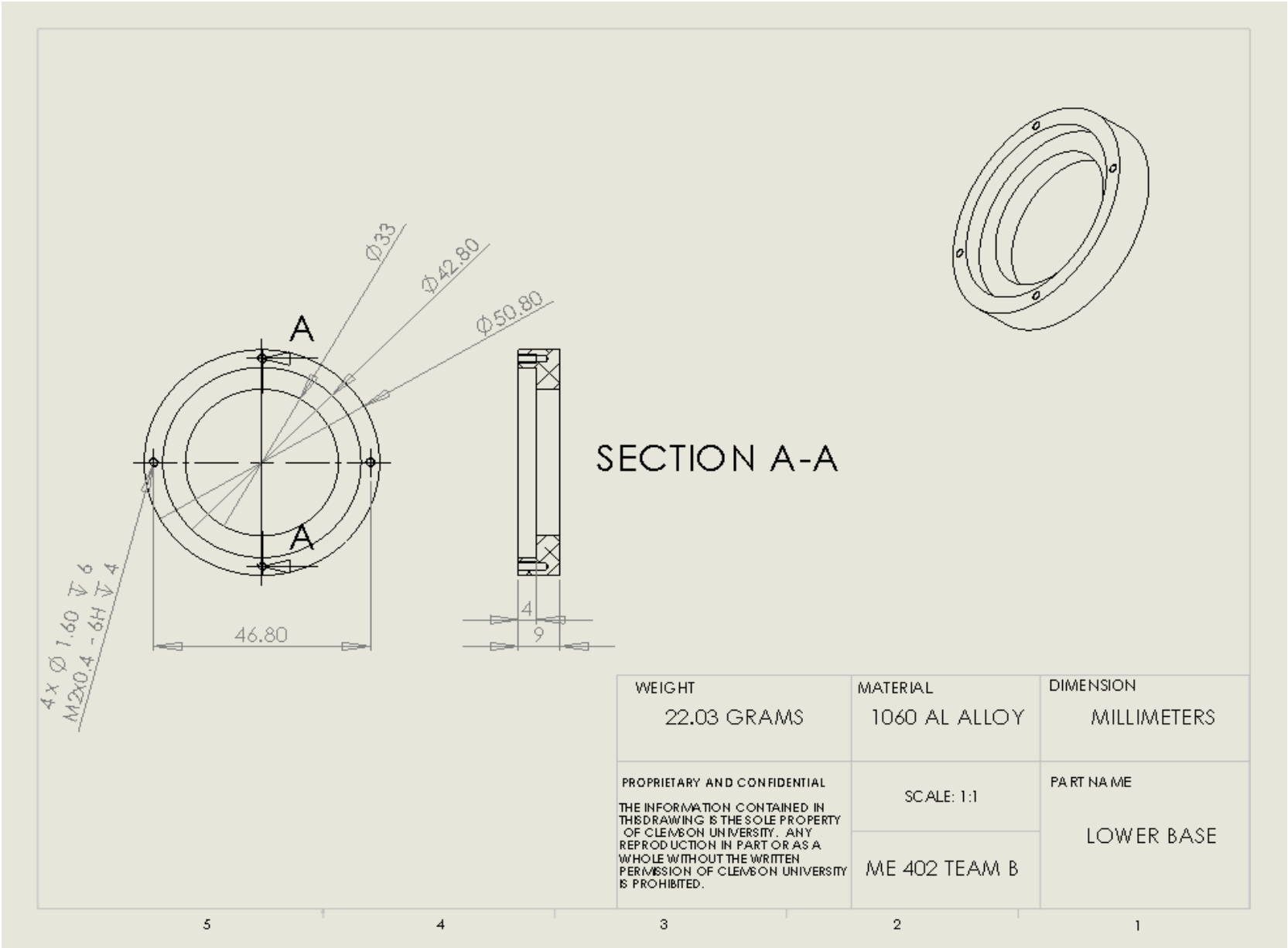
SCALE: 2:1
ME 402 TEAM B
PART NAME
MOTOR MOUNT BOTTOM
5
4
3
2
1


Ø33
Ø42.80
Ø50.80
A
A
SECTION A-A
46.80
4
9
4x Ø 1.60 ↧ 6
M2x0.4 - 6H ↧ 4
WEIGHT
22.03 GRAMS
MATERIAL
1060 AL ALLOY
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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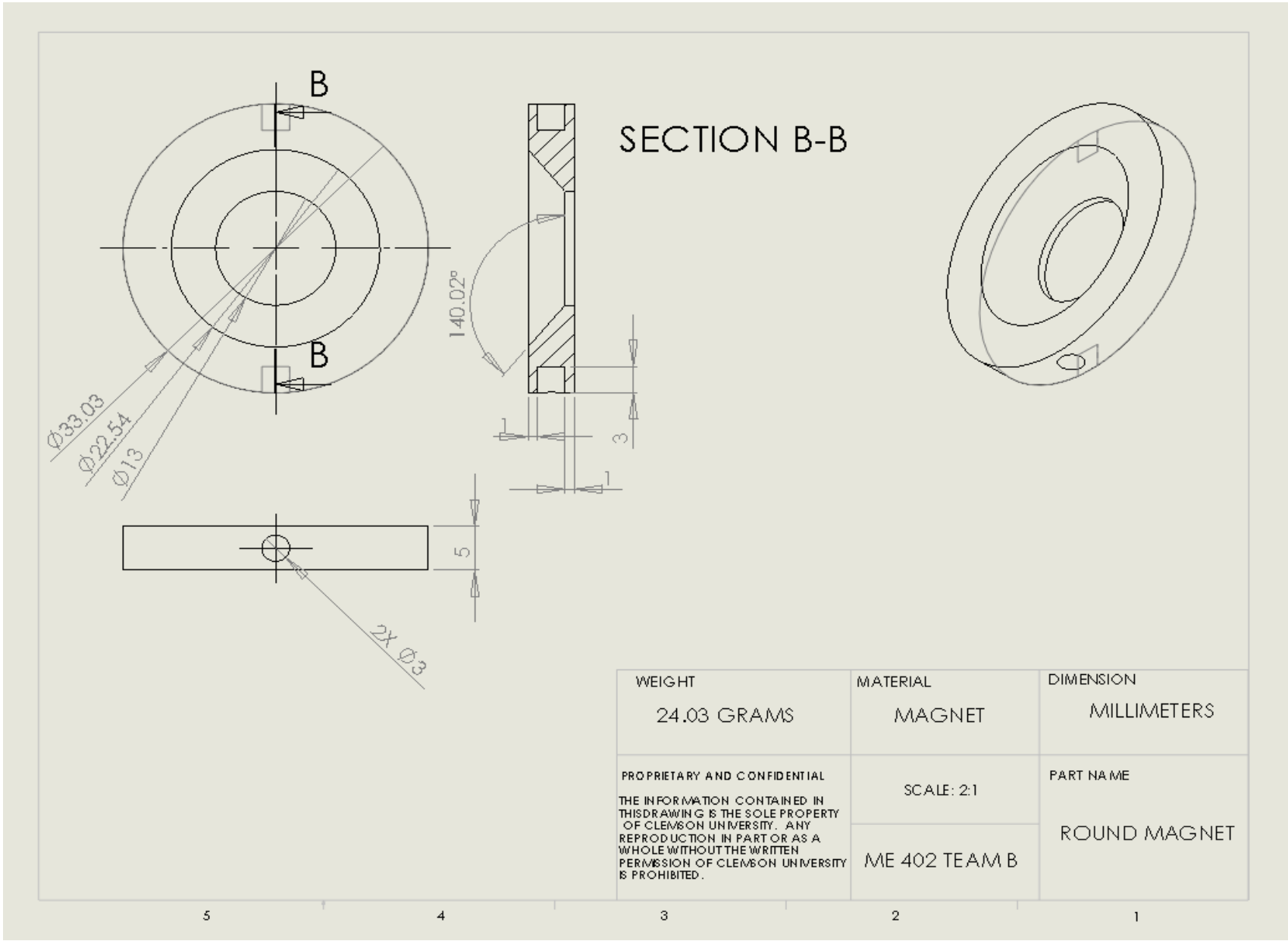
SCALE: 1:1
ME 402 TEAM B
PART NAME
LOWER BASE
5
4
3
2
1


B
B
SECTION B-B
140.02°
Ø33.03
Ø22.54
Ø13
1
3
1
5
2X Ø3
WEIGHT
24.03 GRAMS
MATERIAL
MAGNET
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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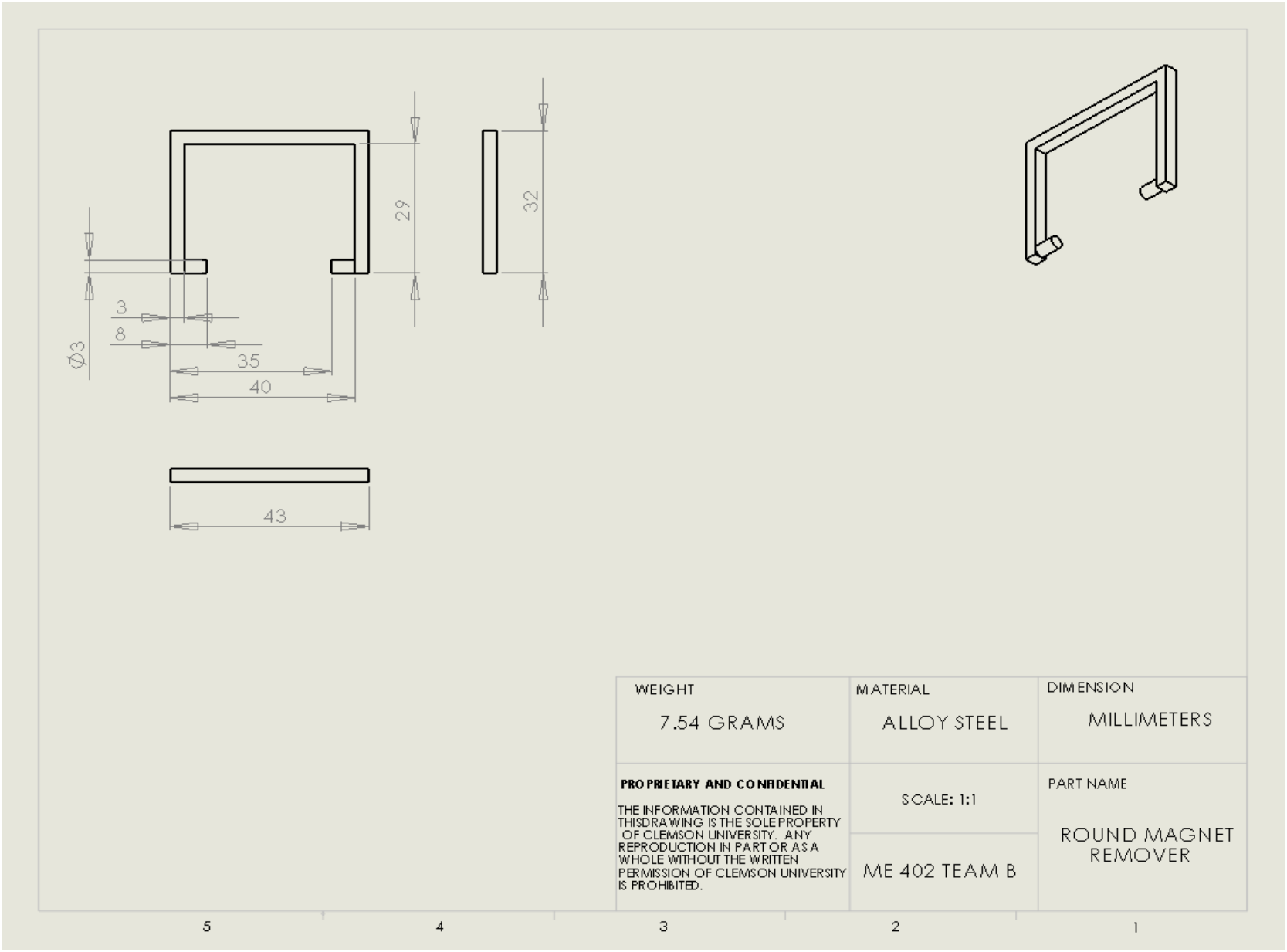
SCALE: 2:1
PART NAME
ROUND MAGNET
ME 402 TEAM B
5
4
3
2
1


29
32
3
8
Ø3
35
40
43
WEIGHT
7.54 GRAMS
MATERIAL
ALLOY STEEL
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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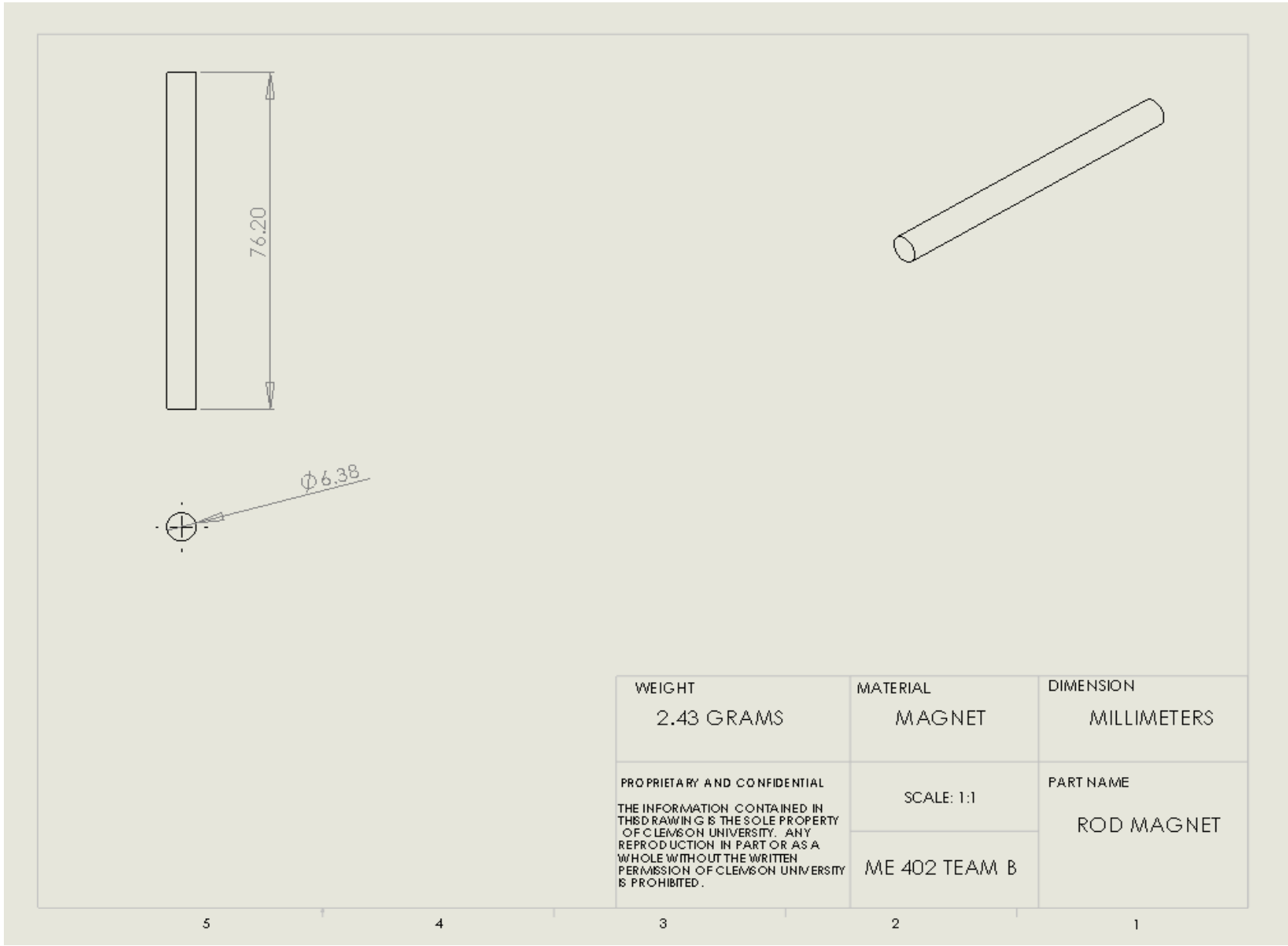
SCALE: 1:1
PART NAME
ROUND MAGNET REMOVER
ME 402 TEAM B
5
4
3
2
1


76.20
ϕ6.38
WEIGHT
2.43 GRAMS
MATERIAL
MAGNET
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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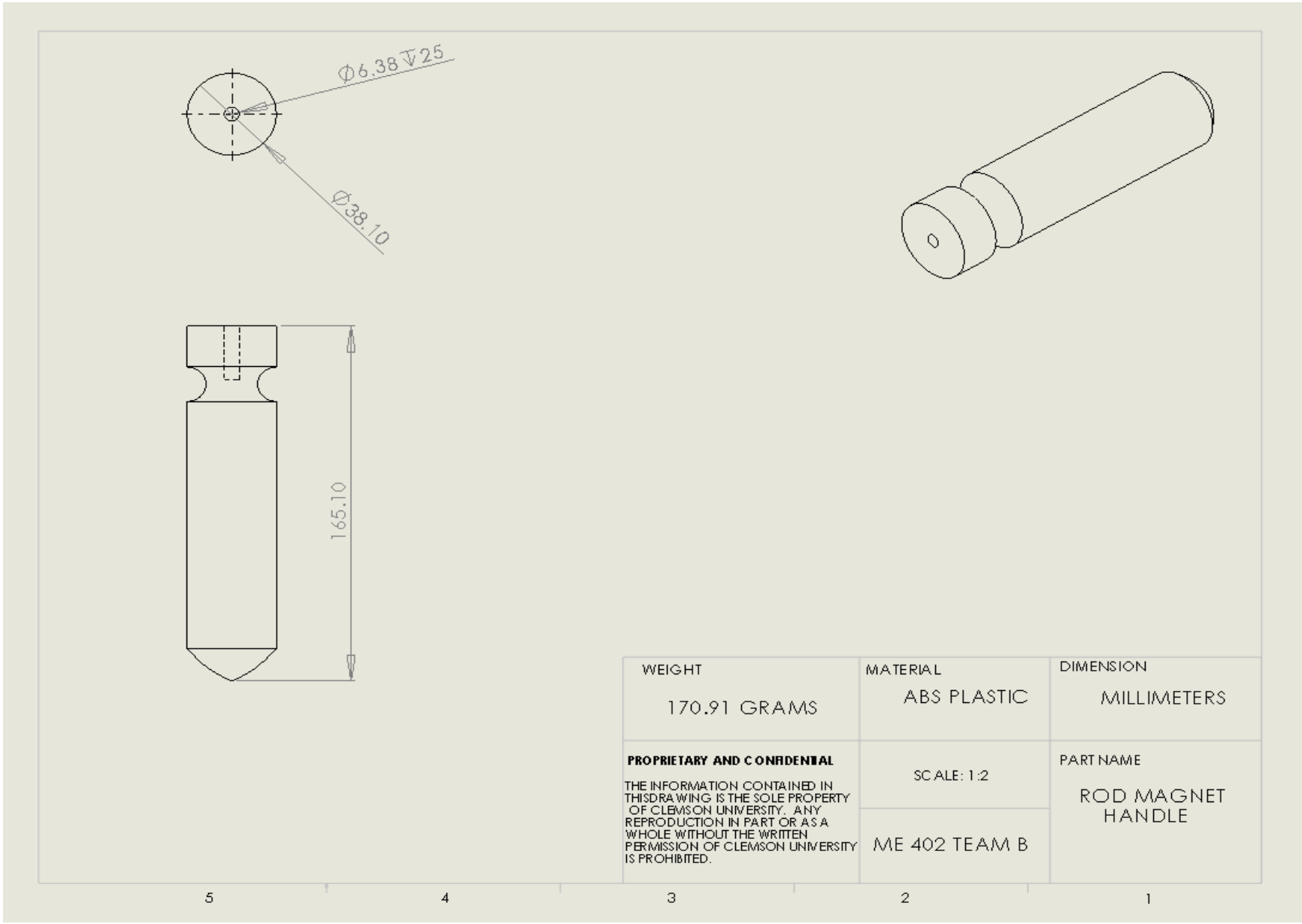
SCALE: 1:1
ME 402 TEAM B
PART NAME
ROD MAGNET
5
4
3
2
1


Ø6.38 ↧25
Ø38.10
165.10
WEIGHT
170.91 GRAMS
MATERIAL
ABS PLASTIC
DIMENSION
MILLIMETERS
PROPRIETARY AND CONFIDENTIAL
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SCALE: 1:2
ME 402 TEAM B
PART NAME
ROD MAGNET HANDLE
5
4
3
2
1

APPENDIX N: BILL OF MATERIALS

BMW RIVNUT - GROUP B - RIVNUT REMOVER TOOL							
BILL OF MATERIALS							
Part Number	**Part Description**	**Quantity**	**Price Each**	**Price Total**	**Custom**	**Procure From**	**Part Number**
A	Motor	1	$662.18	$662.18	No	McMaster-Carr	7200K200
B	Handle	2	$12.25	$24.50	No	McMaster-Carr	6308K530
C	Handle Mount	2	$192.50	$385.00	Yes	Machine Shop	NA
D	Motor Mount Screw	4	$11.86	$11.86	No	McMaster-Carr	91290A256
E	Motor Mount Top	1	$52.50	$52.50	Yes	Machine Shop	NA
F	Motor Mount Lock Washer	4	$2.06	$2.06	No	McMaster-Carr	91169A170
G	Motor Mount Nut	4	$6.91	$6.91	No	McMaster-Carr	90685A041
H	Collet Nut	1	$13.83	$13.83	Yes	McMaster-Carr	90685A070
I	Collet	1	$280.00	$280.00	Yes	Machine Shop	NA
J	Collet Set Screw	1	$7.28	$7.28	No	McMaster-Carr	93245A110
K	Motor Mount Legs	4	$56.88	$227.50	Yes	Machine Shop	NA
L	Base Screws	4	$6.76	$6.76	No	McMaster-Carr	91290A015
M	Upper Base	1	$70.00	$70.00	Yes	Machine Shop	NA
N	Motor Mount Bottom	1	$35.00	$35.00	Yes	Machine Shop	NA
O	Lower Base	1	$87.50	$87.50	Yes	Machine Shop	NA
P	Ring Magnet	1	$150.00	$150.00	Yes	KJ Magnetics	NA
Q	Woodruff Key Seat Cutter	1	$125.00	$125.00	Yes	Whitney Tool	NA
R	Ring Magnet Remover	1	$5.00	$5.00	Yes	Machine Shop	NA
S	Rod Magnet	1	$7.25	$7.25	No	KJ Magnetics	D4Z0
T	Rod Magnet Handle	1	$35.00	$35.00	Yes	Machine Shop	NA
U	Drill Bit "K"	1	$3.28	$3.28	No	McMaster-Carr	2932A22
V	Drill Bit "T"	1	$5.16	$5.16	No	McMaster-Carr	2932A32
W	Static Cling Film	1	$5.00	$5.00	No	Glass Décor and More	NA
X	Strong Adhesive Tape	1	$3.00	$3.00	No	Wal-Mart	NA
						Estimated Tool Cost:	**$2,211.57**

APPENDIX O: USER MANUAL

1. Place plastic film on vehicle body
2. Place magnet around Rivnut®

Figure 75. Placement of Magnet.

3. Remove the threads of the Rivnut® by use of a type "K" drill bit in a portable drill

Figure 76. Drilling Out Threads.

4. Place the tool around the magnet.

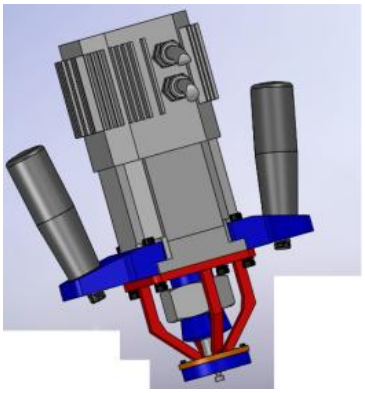

Figure 77. Tool Placed Around Magnet.

5. Engage the woodruff key seat cutter with the Rivnut®

Figure 78. Tool Engaged with Rivnut®.

6. Move the tool in a circular pattern, provided by the base.
7. Remove the tool from the hole
8. Use a type "T" drill bit on the head of the Rivnut® to remove it.

Figure 79. Removing Rivnut® Head.

9. Place a rod magnet inside the hole to remove the once threaded portion of the Rivnut®

Figure 80. Rod Magnet Insertion.

10. Remove round magnet and film from vehicle
11. Install new Rivnut®

REFERENCES

[1]*Ace Rivet & Fastener*. Ace Rivet & Fastener Inc. Web. 15 Jan. 2010 <http://www.acerivet.com>.

[2]*Blind Rivet Nut Tools*. Gesipa Fasteners USA. Web. 15 Jan. 2010 <http://www.gesipausa.com>.

[3]*Blind Rivet Nuts and Studs*. Kendallville, IN: Böllhoff Rivnut, 2010. Print.

[4]*General Repair Procedures*. Integrated Publishing. <http://www.tpub.com/content/elecequipment/TM-10-5411-207-14/css/TM-10-5411-207-14_34.htm>. Jan. 17, 2010.

[5]"Material Data Sheet." *ASM*. Web. 28 Jan. 2010. <http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6>.

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